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A Study of the Spatial Dynamics of some Introduced Avian Species in the Southwest Region of Western Australia

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A STUDY OF THE SPATIAL DYNAMICS OF SOME INTRODUCED AVIAN SPECIES IN THE SOUTHWEST REGION OF WESTERN AUSTRALIA

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BA (Hons)

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DEDICATION

This is dedicated to the memory of
Todd John Powell, 1994-2012

Non sine pulvere palma (Horace (65 – 8 BC)

‘Nothing without dust on the palm’

Or otherwise,

‘The reward cannot be won without effort’

THE SOUTHWEST REGION OF WESTERN AUSTRALIA

(The Southwest Region of Western Australia, Google Earth, 2013b)

ABSTRACT

The Southwest region of Western Australia is a recognised 'biodiversity hotspot', as it possesses high levels of biodiversity and endemism; it also holds a number of species threatened by habitat loss. The arrival of Europeans in the region wrought major changes on the natural landscape. Extensive tracts of bushland were cleared for housing, infrastructure, forestry, farming, and mining. Another challenge to regional biodiversity was the spread of exotic plants and animals (including birds); the latter provide the focus for the present study.

The research examines four bird species that colonised the Southwest region following European settlement: Australian White Ibis (*Threskiornis molucca*); Spotted Dove (*Streptopelia chinensis*); Laughing Dove (*S. senegalensis*) and Laughing Kookaburra (*Dacelo novaeguineae*). The study examines how the feeding and breeding ecology of the species influenced colonisation success and dispersal, specifically in relation to geographic i.e. climate and anthropogenic (e.g. landuse) features of the region. Each of these species has been identified as a 'generalist' feeder, with flexible ecological needs. The species have been able to adapt their food preferences and way of life to living in proximity to human settlements. It appears that each utilised resources made available through human endeavour and activities. It appears that the most rapid spread of invaders occurs in areas of modified habitat, in which the proportion covered by natural ecosystems has declined: i.e. in urban areas, pastoral lands and agricultural areas, although conserved natural habitats have also been invaded.

The results indicate clear associations between the extent of colonisation success in the first wave of dispersal, and anthropogenic phenomena. Such is evidenced by the range expansion of Australian White Ibis into coastal urban areas, within which foraging success is assisted by access to alternative food sources and roost sites; whereas the species' movement inland is linked to habitats associated with dairy farming and cattle production. However, the biology of each species and the extent of its ecological flexibility are also influencing factors, as attested by the wide-spread dispersal of the Laughing Kookaburra throughout the study area. This species possesses physiological features that give it an energy advantage over other species and it possesses social behaviours which offer further ecological advantages.

Although it is a combination of factors: the biological attributes of the species (which define the ecological aspects of its survival), the geographical features of the adopted landscape, and the impact of human imprint upon that landscape that affect the process of biological invasion, the outcomes are specific to each species. This is shown in the development of markedly different patterns of dispersal, as between the two *Streptopelia* doves, despite their arriving in the study area under (approximately) the same conditions, and sharing almost identical ecological profiles. As, despite being released into rural areas, the Spotted Dove retained a localised, mainly urban, population, whilst the Laughing Dove has become spread across both urban and rural environments. This may be due to differences in the ability of each species to tolerate dryland conditions, which appear to better suit the Laughing Dove, perhaps due to similarities in climate between the adopted range and the areas from which it originates.

It is felt that the study has augmented existing knowledge of biological invasion events in the study area, and contributed towards a greater understanding of biological invasion phenomena, particularly those associated with wheat production, processing, and transport. The study design incorporated Geographic Information Systems (GIS) technology as a means of processing large volumes of historical data. The methodology developed for the study could be adapted to other species, regions and eras, provided sufficient data are available. It produces temporal snapshots of changes in distributions, which can be considered in relation to changes in climate conditions and landuse practices.

DECLARATION

I certify that this thesis does not, the best of my knowledge and belief:

I. incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

II. contain any material previously published or written by another person except where due reference is made in the text; or

III. contain any defamatory material.

Signature:

……..

Desireé L Moon

30 June 2013

……..

Date:

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

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1 INTRODUCTION

1.1 Background to the Study:

Whilst conducting prior research on the Australian Raven (*Corvus coronoides*) in urban wetland parks in eastern metropolitan Perth (Moon, 2005), species lists for other birds present where compiled. It was discovered that several species recorded at each site were not native to the area, but were either immigrant, acclimatised or feral aviculture species. In particular: Australian White Ibis (*Threskiornis molucca*), Spotted Dove (*Streptopelia chinensis*), Laughing Dove (*S. senegalensis*), Laughing Kookaburra (*Dacelo novaeguineae*), and Rainbow Lorikeet (*Trichoglossus haematodus*).

Greater interest in them developed as a result of outcomes from a survey conducted for the research to investigate community attitudes toward Australian Raven. Many respondents thought these non-native species 'belonged' to the area, and that the native Australian Raven had 'invaded' it. Also, the non-native species were not perceived as a threat to other species, or as a public nuisance, quite unlike the Australian Raven, which was maligned as a scavenger and predator of young birds. Rather, the Kookaburra was lauded for its cheerful song, the doves for their gentle manner, and the lory, for its colourful plumage.

Extensive field observations undertaken for the research however did not support this poorly perceived view of the Australian Raven. But it did highlight a raft of negative attributes about the non-native species: the Australian White Ibis was just as a voracious scavenger as Australian Raven, the Laughing Kookaburra, just as wily a predator; and the Rainbow Lorikeet, as possessing an equally (if not more discordant) grating song.

The gap between the perceived beliefs about these non-native species raised concerns considered worthy of further investigation: What was the status of their populations in Western Australia, and elsewhere? Is their presence as innocuous as it is perceived? Does their presence have a detrimental impact on local species? What environmental or economic issues are related to them meeting their ecological needs? Are the populations monitored? If not, should they be? Is there cause to indicate that future populations require management?

Whilst initially the aviculture species, Rainbow Lorikeet and then later Sulphur-crested Cockatoo (*Cacatua Galerita*) and Indian Ringneck Parakeet (*Psittacula krameri*), were also to be included in the study, they were eventually set aside for a number of reasons. The Indian Ringneck was immediately excluded due to low data availability, which made it unsuitable for GIS analysis. Although data availability for the Rainbow Lorikeet and Sulphur-crested Cockatoo were sufficient, they were excluded due to other considerations.

Primarily, their inclusion would have expanded the bounds of the present study too far, or required a substantial reduction in the profiles being compiled for each of the focus species, effectively detracting from the stories being told. By concentrating on a smaller number of species, the profiles of those remaining could be suitably detailed as a means of contextualising their colonisation and spread in relation to the study area, as set out in the aims of the study.

Another consideration was that the examination of these other species would not be best served by cursory examination. As, unlike the remaining focus species, which arrived in the study area and established populations either through immigration, or acclimatisation, these others arrived to the study area as a result of accidental (and some say, less inadvertent), liberations. They are all 'cage-birds' that arrived to the study area under permit, to be bought and sold subject to certain permissions, and kept under strict conditions designed to avoid escape. However, despite these precautions each has established populations in the wild.

There are many environmental and economic issues associated with these species that created a wealth of avenues to explore. It was felt that their study warranted broad investigation, including an exploration of the aviculture industry in relation to feral avian species in the state. So although they have not been included here, is not to say their stories should not be told.

1.2 Justification for the Study:

Generally people welcome wildlife into their gardens to improve its aesthetic qualities. Some offer food and water as a way of attracting birds which are both highly visible and often melodious. Whilst the practice is widespread, it is not always in the interests of conservation and the protection of unique and threatened avifauna species, as it often benefits generalist species, some introduced. It seems that generally, "the role played by acclimatised birds and their insidious undermining of the position of native species" (Serventy, 1937, p. 189) is overlooked. The almost ubiquitous view appears to be that if the incoming species presents no obvious threat to humans, livestock, agriculture or iconic biotic species, they are considered "neutral or harmless and possibly even as an ornament to the landscape". In some cases they are seen as a boon, if they are thought to aid in the control of other problem species.

Whilst this may seem of little concern, such views advocate disregard for our endemic species and hint at an ignorance of understanding the potential impact any biotic introduction can have upon local ecosystems, no matter how innocuous it may first appear. There is always a risk that if it becomes established it could "have repercussions which will detrimentally affect the existing fauna" (1937, p.189). The impacts of introduced species on local ecosystems are not restricted to mere competition for resources between a few individuals from a couple of species. They can culminate in a struggle for survival between an existing population and an encroaching one.

The ecosystem dynamics following biological invasion events are complex and are as much a matter of interference as competition: Other than the obvious, there are often:

> …many indirect influences, acting through other species...or the relative skill of two kinds of animal, or a whole string of causes and effects that can be very hard to trace. These, equally with interference...may lead to the replacement of one species, or part of the populations of one species by another – a demographic event of whose interior causes we may be and usually are almost ignorant (Elton, 1958, p. 122).

The present study seeks to investigate 'causes and effects' related to the focus species. In the spirit of Kitching (1986) , it examines how human-made changes to the landscape have aided or inhibited the colonisation and dispersal of the focus species. It also considers environmental, social and economic impacts of the species upon the study area. Tolerance of these invaders as part of the natural mosaic of the study area simply serves to accommodate the dominance of nature by human kind.

It also advocates that resulting environmental, social or economic deficits arising from their intrusion are negligible. It supports a point of view that, where biological invaders are concerned, "the balance of nature" (Serventy, 1937, p.189) will always prevail. However, such an optimistic view perhaps should be balanced by the Malthusian view that "the reproductive potential of virtually any organism or species greatly exceeds the earth's capacity to support all its possible offspring" (Malthus, 1798). It seems prudent therefore that tolerance be born of knowledge, not ignorance.

Whilst diversity may be preserved and protected due to mechanisms that keep populations in check, such as predation and niche competition, we must not overlook the proposition that "…every environment is supporting its maximum population so far as natural conditions allow and...each species is constantly pressing against the bounds of subsistence" (Serventy, 1937, p.189). The assimilation of an exotic species into the local environment therefore, may in some instances, occur as a direct consequence of the displacement of an already present local species. It is important to note that natural areas are not simply perceived as "a vacuum into which we can indefinitely pour stranger species, expecting that it will support them in addition to those already in occupation" (1937, p.190).

Further justification for the research draws inspiration from Charles Elton (1958), in the first book written exclusively about biological invasions. In it, Elton issued an edict about the explosive world in which we live, and warns:

> We may not know where or when the next outburst will be. We might hope to find ways of stopping it or at any rate damping downs its force…an ecological explosion means the enormous increase in numbers of some kind of living organism…the bursting out from control of forces that were previously held in restraint by other forces (Elton, 1958, p.15).

To date, little has changed, other than the rate and extent of biological invasions have increased, along with advances in transport and modification of the natural landscape. Globally, biological invasion events, both "those that occur because a foreign species successfully invades another country and those that happen in native or long-established populations" (1958, p.18) continue. So, despite that in Australia, introduced species represent only "a relatively small proportion of our biota, the exotics have an enormous impact, both economic and aesthetic, which affects every one of us directly and indirectly" (Kitching, 1986, p.5).

The problems associated with introduced species are further compounded by the impact of habitat transformation upon the landscape "due to agriculture and urbanisation" (Krug, 2007, p. 147), a phenomenon not restricted to Southwestern Australia, with "fragmentation of once contiguous habitats common across the Mediterranean regions of the world". Another commonality shared by the study area to other global regions is its renown "for high levels of endemic biodiversity and the extreme degree of imperilment of that diversity" (Cowling, Rundel, Lamont, Arroyo, & Arianoutsou, 1996).

Areas within the Mediterranean biome have been identified as 'biodiversity hotspots' (Myers, Mittermeier, Mittermeier, da Fonesca, & Kent, 2000), identified by the United Nations as being internationally significant, belonging to "a global network" requiring conservation management and monitoring (Stehlik, 2007, p. 245). Therefore, any research project that examines ecosystem change, including the impact of introduced species, is globally significant.

There is little doubt that the homogenisation of local and regional floristic and faunal communities is occurring, and "the intentional or accidental introduction of new species is altering the composition and ecology of long-established biological communities" (Davis, 2003, p. 481). The situation has arisen from the globalisation of trade, transport and travel and changes in climate and land use which "are rendering some habitats more susceptible to biological invasion" (Reaser, Gutierrez, & Meyerson, 2003, p.598).

Globally, experts have recognised the impact of invasive alien species as "one of the most significant negative effects on the conservation of natural biodiversity" (Lee & Macdonald, 1996, p. v). Controls have failed to keep up with the spread of organisms, which intensified due to increased trade and travel (Elton, 1958). In a sense, the endangerment of and threat of extinction of local species is "biological pollution" (McNeely & Strahn, 1996, p.3). The problem is exacerbated by virtue of the fact that the pollutant can "adapt, reproduce, and spread" (1996, p.3) and the conditions created are often irreversible.

With the introduction of the terms 'invasion' and 'invasive' into the discussion, it seems prudent to clarify what they imply within the present study. Generally, reference to a biological 'invasion' implies the "mass movement of organisms into new territory" (Scott & Stocker, 1995, p. 643), whether due to changed environmental conditions in their historic range, or translocation into a new geographic range, not a militaristic style of attack or assault on an area.

The term ‘invasive’, is referenced from an ‘ecological’ or ‘management’ perspective, referring “to the spread of a non-native species in a geographical area” (De Milliano, Woolnough, Reeves, & Shepherd, 2010, p. 2). Whereas in management terms, it refers to a species “whose introduction, spread and abundance impact on social, environmental and economic values or has the potential to cause damage” (2010, p. 2). In terms of the present study, reference to an ‘invasive species’ identifies it as one which has “spread beyond their natural range and cause or have the potential to cause adverse impacts to social, environmental and economic values”.

The negative impacts of non-native species on their adopted range are not always clearly identified i.e. competition between native species for resources resulting in a population decline (and possible extinction). Further threat is present when fertile, non-native species hybridise and modify or dilute species DNA.

For example, for some forty years, it has been reported that within the Blackwall Reach Reserve, situated on the banks of the Swan River, an introduced Corella (probably a Long-billed Corella, *Cacatua tenuirostris*) shares a nest hole with a native Galah (western nominate race, *C. roseicapilla assimilis*) and has produced hybrid progeny (Lauva, 2009). Other records provided by Department of Agriculture and Food Western Australia [DAFWA], Invasive Species Development Officer, lists a call from a Mundaring resident (31 October, 2007) describing a “sulphur-galah hybrid has taken up with a galah and defending a nesting box” (Personal Communication, Marion Massam, 2 November 2007). The note concludes that the WA Museum states that “some hybrids are fertile”.

Another issue related to non-native species is that they may harbour pathogens harmful to local species. Historically the impact of invasive species has focussed on “harm to human and animal health, agriculture, and other economic interests, rather than on harm to biodiversity and natural ecosystems” (McNeely & Strahn, 1996, p. 4). It is important that clearer understanding of the impact invasive species have on natural ecosystems is achieved. To succeed in this, strategies are demanded to “turn the tide against harmful invasives...should incorporate expert advice on both science and policy” (1996, p.5).

Other than invasive species, the impacts of urban development have also had “a major effect on biodiversity as a result of their magnitude, intensity and permanence” (McKinney, 2002, 2006). Reduced biodiversity in urban areas adjacent to natural areas has been well documented (Crooks, Suarez, & Bolger, 2004; Sewell & Catterall, 1998; Turner, Nakamura, & Dinetti, 2004). A decade of significant urban growth within the study area, “makes the issue of suburban biodiversity conservation particularly significant as avian communities may still be adapting” (Crates, French, & McClean, 2011).

The current view is that suburban bird communities are already "dominated by a homogenous collection of 'urban exploiters'(Marzluff, Bowman, & Donnelly, 2001; Turner et al., 2004). This includes introduced species which threaten native species "sensitive to disturbance" (Crates *et al.*, 2011, p. 341). The protection of these 'at risk' species requires conservation planning and management. The value of maintaining and protecting biodiversity of plant and animal populations has been widely recognised and ratified in international conventions and treaties including Convention on Biological Diversity; Climate Change Convention; and Convention to Combat Desertification.

In the end though, ideals have to be translated into dollars and the "economics for the Noah's Ark problem" (Perry, 2013) reconciled, which is challenging. However, put "simply and eloquently...we must never give up hope" (M. Rands, 2002, p. 21). Many however only come to conservation reluctantly, and opt to enjoy, rather than protect, especially so in regards to birds. Creatures that are visible and audible, beautiful and fascinating, and which if "we simply stand by...are mostly not going to survive" (Harrington, 2000).

The roles biological processes play in sustaining the environment are important, particularly ecosystem function, within which birds a prominent role (seed pollination, dispersal, invertebrate control, nutrient recycling). Changes in bird species diversity is indicative ecological change is occurring (Nix, 2001, 2003). Although at times the solutions sought may appear to be "contrasting and conflicting", protecting biodiversity demands nothing less than "the engaged participation of civil society" (Wardell-Johnson, Pullar, Smith, & Wardell-Johnson, 2007). However, problems are not limited to impacting biodiversity levels. The consensus view is that the "scope and cost of biological alien invasions is global and enormous, in both ecological and economic terms" (IUCN, 2000, p. 3). Therefore, it is, perhaps, timely to direct discussion toward the economic impact of invasive avian species.

In Australia, damage to horticultural crops by birds, though not specifically introduced species, causes in excess of $300 million annually (Tracey, Bomford, Hart, Saunders, & Sinclair, 2007). There is much uncertainty about what constitutes suitable controls, due to variability in both behaviour and movements. Controls are further constrained by legal, environmental and social issues relating to the techniques that can be applied.

A priority for stakeholders is to improve the "ability to predict patterns of bird movement" (2007, p. iii). The use of GIS technology as an analytical tool to interpret historical sightings data, has allowed the construction of detailed maps showing the spread of the focus species since colonisation. As such, the methodology could be adapted to investigation of other species, in other regions, over different time-periods. Whereas a great deal is known about other plant and mammal pest species in Australia, little is known about pest birds. This deficiency needs to be addressed by the instigation of research to "improve knowledge of pest bird ecology, diet and patterns movement and damage" (2007, p. x).

The Inventory of Exotic (non-native) bird species (2007) lists 236 species known to be in Australia, twenty of which have established feral populations across parts of mainland Australia. Many of the others held in captivity were being kept in "in low-security cages in private aviaries" (Tracey *et al.*, 2007, p. xiii). Within Western Australia alone, Long reports "At least fifty species of foreign birds have been introduced into the wild in this state" (1988, p. 5), a number of which are a result of aviary escapees.

A key responsibility of Government is to identify economic and environmental risks that may eventuate should an exotic species be freed from captivity. This has been addressed to some extent by a risk assessment model developed by Bomford (2003). The model seeks to evaluate " a range of factors for an exotic bird species" (Tracey *et al.*, 2007, p. xiii), such as climate matching, history of establishing populations in other places and its 'pest status' in other countries as a means of calculating a score ranging from 'low' through to 'moderate', 'serious' or 'extreme' (Tracey *et al.*, 2007). An exotic species present in the wild is not immediately deemed a pest, it is only after it has had "a negative impact on a valued resource" (2007, p. xiv), they are identified thus (i.e. damage to crops or infrastructure, impacts on local native species).

Other *possible* damage by pest birds, specifically the focus species includes damage to cereal and oilseed crops; damage to aquaculture; taking and contaminating animal feed at livestock and production facilities; eating and fouling pasture; damaging seedlings in plantations; competing with native species for nest holes and food; posing a risk to aircraft in terms of air-strike (both on runways and in the air); and nesting in engines; being a social nuisance when roosting or nesting in urban areas; or causing property damage; spreading disease to people and fauna, attacking people; or faecal contamination of soils or waterways.

The methods and objectives of the present study are not directed towards the assessment of the status of the focus species as pests, but to investigate dispersal in relation to landscape features. Also, to identify the environmental, economic and social problems that their populations have wrought, in order to advance understanding of the species and aid the development of management strategies and controls. Findings from a recent study (Cassey & Henderson, 2012) confirm this as a valid enterprise.

They report that "exotic pets and stowaway animals" present high risks "for the introduction and establishment of new invasive animals in Australia". They urge increased efforts at collecting "comprehensive and reliable records on the likely origins of emerging threats". Advances in travel mean that Australia is no longer protected by its isolating oceans. Its biodiversity and regional endemism is being eroded by a plethora of exotic animal and plant pests. Justification for the present study therefore rests on the following assertions (i) it will augment existing knowledge of avian invasion events; (ii) ascertain factors that enhance or inhibit colonisation success; (iii) identify problems or threats resulting from avian invasion events; and (iv) aid the development strategies to maintain biodiversity.

In closing, a final aide memoire, that in Australia, and most certainly the study area, Southwest Western Australia, exists one of the richest bird faunas in the world:

> not perhaps in diversity of kinds, or even in abundance of individuals, but certainly in the many peculiar and strikingly distinctive species which are found nowhere else (MacDonald, 1973, p. 9).

It is a heritage worth safeguarding, and which demands no further justification for research endeavours toward this purpose.

1.3 The Present Study:

This present study adopts a multi-disciplinary approach to the examination of the process of biological invasion in relation to the following species: Australian White Ibis (*Threskiornis molucca*), Spotted Dove (*Streptopelia chinensis*), and Laughing Dove (*S. senegalensis*) and Laughing Kookaburra (*Dacelo novaeguineae*).

The integration of several conceptual and theoretical approaches brings the present study in line with accepted practice for the study of biological invasion phenomena, as a means of showing "an intense understanding of multiple disciplines" (Lockwood, Hoopes, & Marchetti, 2007, p.vi). The study of invasion ecology is complex and "integrative, requiring its practitioners to understand (at the least) economics, evolution, population genetics, biogeography, and ecology". Research of this manner requires a combination of these concepts to "find ways to control the flow and impact of non-native species".

Central to the study design is the use of Geographic Information Systems (GIS) software analysis. The integration of historical data from several reliable sources into a comprehensive database to underpin the analysis allowed for a fuller interpretation of the spread of the species throughout the study area since their arrival. The use of GIS enabled the production of maps displaying patterns of temporal and spatial dispersal.

Although no longer a 'new' technology, as it has been around in its current form since *circa* 1990, GIS "demonstrates the potential for utilising advances in mapping techniques and available data sets" (Freeman, Clark, & van Heezik, 2011). It offers a practical tool for use by land and conservation managers to gain insights into spatial perspectives related to a species. Although developed for the present study, the methodology can be applied to other species and eras. It demonstrates that multiple, and non-digitised datasets comprised of historical data can be adapted for technology.

Whilst the incorporation of GIS allows the production of detailed maps and spatial analyses pertaining to the focus species, it does not generate insights into the factors that influenced the patterns related to colonisation and dispersal.

To this end, the present study draws from an array of conceptual and theoretical frameworks including invasion biology, population dynamics, biogeography and ecology.

1.4 Aims of Research:

There are several aims implicit in the research: To compile a comprehensive dataset of historical data suited to analysis; to identify spatial and temporal patterns of dispersal of the focus species throughout the study area subsequent to colonisation; investigate how the ecology the species has influenced patterns of spread; and examine distributions in relation to various geographic and anthropogenic features of the study area. Further, to consider the environmental, social and economic impacts of the species on the study area.

To assist in achieving the aims of the study, the database compiled will be analysed using Geographic Information Systems (GIS) software. Overall, the study design is intended to examine the data as a means of validating or rendering invalid the following hypothesis:

That the different colonising avian species have adopted different colonisation strategies reflecting their own biology in relation to the physical and ecological environment of the colonised landscape

To investigate the hypothesis, the following five research questions were devised:

1) What variations in spatial-temporal patterns of spread emerge when Geographic Information Systems analysis is applied to historical sightings data for each of the focus species?

2) How are these patterns associated with the ecological needs of the species?

3) What roles do geographic factors, e.g. climate features and biotic distributions, influence dispersal?

4) How have anthropogenic factors, e.g. human activities and landuse, influenced the distributions?

5) Do the focus species have a history of colonising other regions within Australia or other countries?

The formulation of these questions binds the lines of enquiry to the present study. The theoretical frameworks underpinning the research are now presented.

2 THEORETICAL FRAMEWORK

2.1 Literature Review:

There were a number of conceptual constructs explored in the development of the research framework. This review examines those central to the study, presenting texts that framed the research parameters. It takes in texts pertaining to invasion biology, population ecology, ecology, island biogeography, and ornithology and extends to general themes inherent in the research. It also profiles texts that assisted with developing the technical aspects of the study.

2.1.1 Invasion Biology:

A foundation text of the study, and indeed the first work consulted with a view of developing the proposed research, was *The Ecology of Invasions by Animals and Plants* (Elton 1958, p. 34). The text, the first of its kind, examined the impact of biological invasion upon local ecosystems. The author, Charles Elton, is considered a founding father of the study of ecology whose interests in animal interactions pioneered new fields of research and endeavour. The text is still widely cited today (it was reprinted in 2000 with a preface by esteemed biogeographical researcher, Daniel Simberloff).

Although others had attempted to investigate the premises of invasion biology prior to his text, Elton unified ideas and concepts which became central to study of the phenomenon e.g. interdependence and the phases of invasion. The text also introduced the concept of 'ecological resistance', the conditions that kept invaders out of natural communities and prevented them surviving in areas they attempted to colonise.

The text also addressed the ways in which human trade contributed toward the obliteration of distinctive plant and animal communities that had established over millennia. In it, Elton discussed the possible impacts and implications for long-term diversity and conservation of unique and endemic species, and gravely warned:

> No one really knows how many species have been spreading from their natural homes, but it may have been tens of thousands, and of these some thousands have made a noticeable impact on human life: that is they have caused the loss of life, or made it more expensive to live. If we look far enough ahead, the eventual state of the biological world will become not more complex but simpler – and poorer (Elton 1958, pp 50-51).

He went on to lament that although the arrival of a new species to an area usually began with a very small core population, often it quickly grew "to an 'Autumn Rivulet' and then not infrequently to a flood" (1958, p. 61). Once it reached that extent, often "its movement is seldom absolutely checked except by natural limits of the environment".

In the text Elton also identifies the most ‘invasible’ lands as those under cultivation, “or those much modified by human practice" (1958, p. 63). A good example of this he said, could be found in the Starling (*Sturnus vulgaris*), whose "headquarters was in cultivated and urban lands" (1958, p. 75). This is why, he says, the future management of introduced species is best addressed by changing people’s attitude to the landscape, rejuvenating modified areas, and preserving areas of remaining wilderness rich in natural communities. It is essential to foster fundamental knowledge about the balance between populations, “and the kind of habitat patterns and interspersion that are likely to promote an even balance and damp down the explosive power of outbreaks and new invasions." (1958, p. 110). Experience has shown us that introduced animals can replace, or cause a reduction in numbers of native species.

Also, suggests Elton, as the wilderness is being depleted, there are lessons that can be drawn, and it would be beneficial if we learned “how to introduce some of its stability and richness into the landscapes from which we grow our natural resources” (1958, p. 155). The aims in conservation need to extend toward the preservation of wild species against human exploits, but a means of “attaining the highest productivity from exploited lands."

In terms of the present study, the style adopted by Elton in his text helped formulate several themes integral to the study design. Specifically, to relate the biology of the focus species to ecological practices (feeding, nesting, roosting, breeding) as a means of identifying the colonisation strategies and adaptations developed by each to survive in the adopted landscape, as well as examine how these strategies influenced colonisation success and dispersal, and to consider the impacts of their arrival in relation to local ecosystems.

Also consulted was *Dynamics of Biological Invasions*, (Hengeveld, 1989). Unlike Elton, who adopts a descriptive and interpretive style to the study of the phenomenon, Hengeveld takes a more clinical approach. The text presents several perspectives from within which biological invasion events can be viewed, including: ‘The Ecological’, ‘The Population Genetic’, ‘The Epidemiological’, ‘The Biogeographical’, and ‘The Mathematical’. Whilst familiarisation with these were insightful to some extent, the advice provided, was, in the end not central to the formulation of the theoretical framework.

However, the text did present some interesting ideas, including the point of view that invasion events are common occurrences that amount to less than “typically spectacular phenomena” (1989, p. xi), which are often mistakenly regarded as “rare and threatening”. Rather, he says, all species ranges should be seen as being in a constant state of change, reflected by range expansions, contractions and shifts, upon which it will become “impossible to discriminate between typical invaders and non-invaders”.

This view is somewhat opposed to those expressed by Elton, who felt that the advent of biological invasion events, if left unchecked, posed a threat to global biological diversity and left unchecked would make the biological world both simpler, and poorer.

Whilst there are many uncertainties related to the study of invasion biology, what is certain is that some species possess properties which enable them to invade foreign communities more easily than others (Leston, 1957). Whilst what these are remains under investigation, it has been ascertained that foremost amongst them is the mobility of the species.

This is because during the first phase of the invasion, there is unoccupied space available and lower competition pressure between established species and the invading species. At which point , "an equilibrium is formed between the number of immigrants and that of the established species which may eventually die out due to excessive competition pressure" (Hengeveld, 1989, p.4). However, this leads to discussion related to '*Equilibrium Theory of Island Biogeography*' (MacArthur & Wilson, 1967), which is discussed later.

The text by Hengeveld also details 'The Advancing Wave Model', which has earned criticism as being too concerned with "the spatial progression of qualitatively advantageous traits and failing to consider ecological factors and processes. The focus should not be too narrow, says Hengeveld, with ecological, biogeographical and population genetics perspectives all needing to be considered. Whilst this model was considered as a conceptual framework around which to base the present study, another was found to be more suitable. Presentation of the selected model forms the basis for the ensuing discussion.

The theoretical framework for the present study incorporates the *Invasion Process Model* (Lockwood *et al.*, 2007). The adaptation of the model to the present study is shown in red, below (Figure 2.1). The model was selected as it provided a way of categorising the sightings data collected for the GIS analysis into subsets that could be analysed temporally and spatially, which is fundamental to any geographic enquiry.

Based on the model, the sightings records were demarcated into three chronological periods: Era A, 1898-1953; Era B, 1954-1980; and Era C, 1981-2007. The model also permitted discussion as to how the focus species arrived to the study area i.e. 'Transport'. It also provided a forum for discussion of the effect of the focus species on their adopted landscape i.e. 'Impact', such as ecosystem damage, threats to local biodiversity, damage to agricultural and horticultural crops, property damage and the potential spread of pathogens.

Importantly, the model proposes that biological invasion events are not instantaneous, but the product of a prolonged, complex interplay of biological, ecological, environmental and social factors. Like many, the authors were influenced by the work of Charles Elton, and cited his greatest legacy as "recognition that ecology was a distinct discipline from biology, and that ecologists had a large role to play in how society dealt with the problems it faced" (Lockwood *et al.*, 2007, p.5). The present study, although primarily geographic, hinges upon investigation of the role the ecology of the focus species in shaping the colonisation strategies each adopted, as a means of contextualising the extent of colonisation success and dispersal. In doing so, the text by Lockwood *et al.* was found to contain many applicable notions.

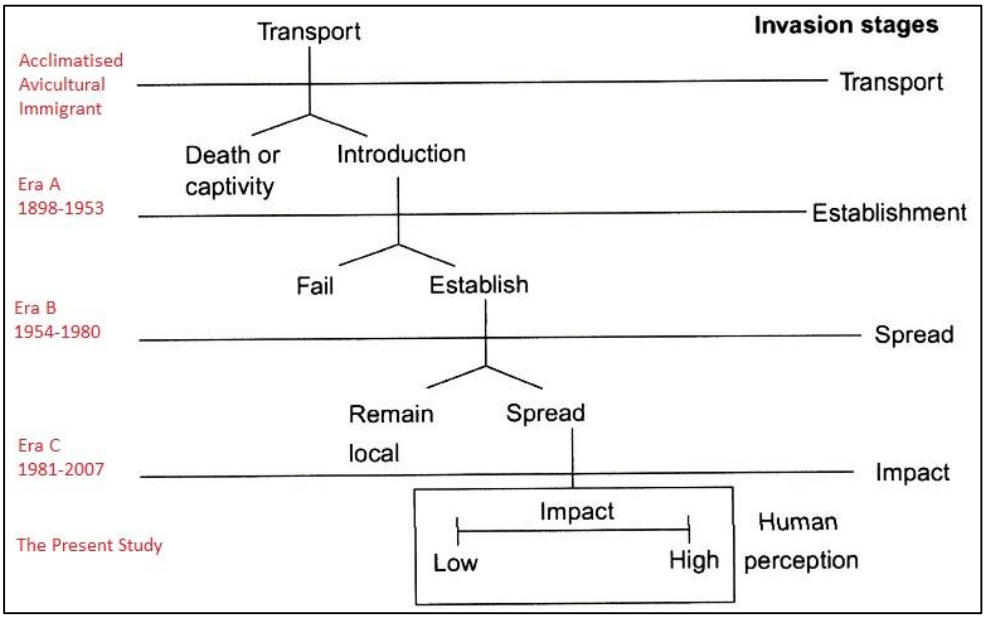


Figure 2.1: *Invasion Process Model* adapted to the Present Study
(Adapted from Lockwood *et al.*, 2007)

An issue raised early in the text is the terminology used to describe biological invasion phenomena, which at times evokes "anthropocentric concepts that are militaristic and pejorative" (Lockwood *et al.*, 2007, p.7). The subject has attracted the attention of numerous researchers including Slobodkin (2001), Simberloff (2003), Brown and Sax (2004), and Cassey, Blackburn, Duncan and Chown (2005).

All discuss the scientific and sociological implications associated with terminology and how it is used. Generally, it is accepted the term 'invasive' applies when a colonised species causes a demonstrable "ecological or economic impact" in the area it has invaded (Lockwood *et al.*, 2007, p.8). Whilst examples of this are drawn from the case-studies, no assessment is made of the status of the focus species as to whether it is qualifies as an 'invasive' species. The future use of the term 'invader' or 'invading species' is simply an attempt to identify it as a species not indigenous to the region, but as one that has 'come into' it.

But neither, they say, should a colonised species be identified by means of "a dichotomous classification i.e. invasive or not" (2007, p.8), when it has been shown that invasion is a process resulting from a colonising species overcoming various barriers and subverting "standard ecological principles". Rather, it is best to "start from the beginning and work our way forward" (2007, p.8).

Prior to being identified as 'invasive', the non-native species "must pass through at least three stages before they are able to inflict ecological or economic harm". Each arrival commences with the transportation of individuals from their native range, into the adopted range.

Survivors must either establish a self-sustaining population within the new environment, or become extinct. Once established, a feral population may become abundant and increase its geographic range, or, remain "small in numbers and local in distribution" (2007, p.9).

Generally, a non-native species only causes economic or ecological harm once its population is widespread and prolific, at which point it is identified as 'invasive'. By viewing biological invasion as a process, comprised of distinct stages, the role of humans, "either as facilitators or inhibitors of transitioning a stage" (2007, p.9) can be identified. The stages are by no means absolute; rather, they "represent biologically identifiable steps along the path to becoming an invader". Just as the authors regarded this model as a viable one for their investigations, it was considered apt for the present study.

At this juncture, Lockwood *et al.* turn to the views of Williamson (1996): that passage through each discrete stage is possible only after overcoming a series of 'barriers'. Consequently, not every colonising species with the chance to transit a stage do so, only 5-20% succeed – the average being 10%. The pattern identified was subsequently incorporated into the '*Tens Rule*', which essentially considers that the success or failure of each species to transit each stage is likely attributable to how forbidding the barriers are, as well as how easily the species navigates them. The task arising for researchers, they say, "is to find a way to sift through all the non-natives that will not cause harm to find the few that will" (Lockwood *et al.*, 2007, p.10).

In relation to the present study, the approach of examining the colonisation and dispersal of the focus species in terms of the 'barriers' and 'bridges' that inhibited or assisted their transition through each invasion phase is adopted. However, it does not examine the rate of colonisation success of the focus species in terms of the rule specifically. The rule is discussed further later in the chapter, when the work of Williamson is reviewed.

In returning to discussion on the *Invasion Process Model*, the authors press the advantages of adopting it. Firstly, it removes any ambiguity that may result from a species being labelled as invasive when it causes problems in some locations but not others, despite sharing common traits that may aid it in becoming invasive in other areas. Secondly, it moves discussion away from the simplistic dichotomy about invaders, as each must first:

> …confront a host of extrinsic forces that determine whether they will persist into the future...including competition, predation, parasitism and other interactions between two (or more) species" (Lockwood *et al.*, 2007, p.14).

Other than these ecological barriers, there are also random variables e.g. flood, fire and ice. The response of the colonising species is also influenced by its previous history, creating a situation whereby "one set of extrinsic forces modifies the effect of the other, and the species themselves… modify the magnitude and extent of the extrinsic forces" (2007, p.15).

These complex dynamics make it difficult to get a clear understanding of what determines the extent of success of a non-native population, if the focus is limited to "one side of the dichotomy or the other (2007, p.15). Another benefit of contextualising biological invasion events within the parameters of the model say these authors, is it aids in identifying the role human interactions play in determining the outcome (i.e. success, failure) of non-native populations.

In many instances, biological invasion events are initiated by humans as a result of either, "purposefully or inadvertently transporting individuals beyond their natural range" and releasing them. Whilst knowledge about this stage of the invasion process is growing, the focus remains on the human impact on ecosystems in which non-natives are trying to settle. Nor are human actions limited to only benefiting invaders, as people also "serve to strengthen the barriers" between the stages of invasion, by means of "socio-political actions" or more directly, eradication (Lockwood *et al*., 2007, p15).

Although, not all the movements of non-native species into an area beyond its historical range are a result of human actions, but rather, immigration: movement assisted by naturally occurring phenomena, i.e. riding ocean currents or prevailing winds. The query that arises is "whether human-mediated transport is qualitatively different from natural colonization events" (2007, p.19), other than it being more varied and dynamic than those that occur naturally.

What is not in dispute is the knowledge that modern transport methods enable the trans-location of species to occur within greatly reduced time-frames (hours, not months or years). Further, species assisted by human transport methods are more ecologically diverse than those that disperse by natural means. As well, the geographic scale of dispersal is often greater than those that disperse naturally. Where consensus fails, is the extent to which human assisted invasions differ from natural colonisations (Brown & Sax, 2004; Cassey et al., 2005; Vermeij, 2005).

These concepts relate to the present study in so much as the focus species included were introduced into the study area as a result of immigration, as in the case of the Australian White Ibis, Or through deliberate human actions, such as the Spotted Dove, Laughing Dove and Laughing Kookaburra, which were all acclimatised species.

As mentioned previously, the species Rainbow Lorikeet, Sulphur-crested Cockatoo and Indian Ringneck Parakeet that were also initially considered for the present study, arrived to the study area as aviculture species, and subsequently escaped or were released from captivity. The point is that, all of them, other than the Ibis, benefited from human assisted passage, which made it possible for them to traverse isolating distances and overcome the geographic barriers (desert and sea) that restrict natural colonisation processes.

Another concept put forward by Lockwood *et al.* that has application to the present study is that of 'transport pathways', which the authors define as " routes between the source of non-native species and the recipient location for these species" (Lockwood *et al.*, 2007, p.19 (2007, p.34). The strength of a pathway depends on the number of species that utilise it and the viability of the populations that move along it. The stronger the pathway, the greater the likelihood a non-native species will establish in areas through which it passes. Whilst Lockwood *et al.* relate the concept to the transport of species via global trade routes, within the context of trans-continental transfers; it also has some relevance to the present study.

Although initially dispersal of a non-native species may be less hindered by following an established transport pathway, it does not guarantee its survival in the landscape to which it is arriving. Put simply, a colonising species "will not survive in a recipient region where their basic physiological requirements are not met" (Lockwood *et al*., 2007, p. 60). This was not the case of the Laughing Dove, whose ecology was well suited to the area.

The state of individuals may vary considerably across the geographic range colonised, due to a lack of available ecological resources. A species that moves into an area with limited resources, results in individuals of that species having poor condition. Often species that traverse established transport routes experience less than ideal ecological conditions *en route,* and despite prolonged persistence it is unlikely they will establish a healthy, viable population.

Whilst the focus species in the present study show successful adaptation to their adopted environment, analyses of the sightings records show reducing populations along some transport routes, which at times resulted in range retraction. However, retractions are less likely to occur along transport vectors that have experienced ecological disturbance, a major contributing factor toward colonisation success. One of the most commonly cited maxims in the study of biological invasion is "Disturbance facilitates invasions" (2007, p.76).

The role of such and its effect on species diversity is fundamental to most investigations. Elton (1958) first put forward the proposition that most non-native species are located in areas altered by human disturbance. Sometime later this was attributed to the creation of 'invasion windows'(Johnstone, 1986), of which non-native species were able to utilise to make inroads. In effect, "disturbance creates vacant space, releases resources, and alters species interactions" (Lockwood *et al.*, 2007, p.76). Disturbance was identified as "a necessary precursor to the establishment of many non-native species" (2007, p.76). Whilst this facet of biological invasion has been well documented (refer Hobbs & Huenneke, 1992), the more it is examined, the more complexities are identified. However here is not the forum for discussion.

Although, say Lockwood *et al., e*cosystem disturbance does not only benefit non-native species, as some native species also able to adapt to modified environmental conditions. Essentially, for a non-native species to benefit from the effects of disturbance it requires sufficient individuals present to propagate at the affected site.

This can only occur if, ecologically they are the right sort of species for the site. Therefore, say the authors, debate as to whether disturbance facilitates or impedes invasion is moot, "because the effects of disturbance are context specific" (2007, p.87). Still, it is important to recognise that human-assisted transports are responsible for introducing a greater number of species than would occur because of immigration. Of those, more are "well adapted to human disturbances" than those that require unspoiled habitats, meaning "that anthropogenic disturbances promote the establishment of most non-native species" (2007, p.87).

The preceding discussion is pertinent to the present study, specifically, in terms of the Laughing Dove, as it utilised transport routes to disperse into the Wheatbelt. In relation to the other focus species, all have proved successful in 'disturbed' habitats, e.g. urban areas, which are recognised as having "a similar signature as agriculture in terms of its effects on non-native species" (Lockwood *et al.*, 2007, p. 94). In relation to the Laughing Dove and White Ibis, they colonised widely in cultivated and pastured areas. These inroads to colonisation success are a consequence of the development of primary industries including forestry, farming and cropping, their spread, the ecological legacy of economic growth.

In terms of the concentration of populations of the focus species in urban areas, the viewpoint that, "non-native species richness increases with level of urbanisation, or is correlated with human population density" is well supported (Holway, 1995; Kennard, Gould, Putz, Fredericksen, & Morales, 2002; Vila & Pujadas, 2001). This appears the case in regard to the study area, given, not just the extent of populations of the focus species, but of other non-native species (including sedges, grasses, insects, amphibians, mammals and other birds), some of which are already recognised as 'pest' species.

Whether a non-native species becomes established and then disperses further will depend on "a subtle difference in population growth but a fundamental difference in biology" (Lockwood *et al.*, 2007, p. 108). To *establish* a species must first survive in a specific location and have at least some reproduction success. To *spread*, it must experience population growth, not stasis, to drive individuals to at least one new location in search of ecological resources, whereupon its survival depends on whether they are adequate.

Whilst this approach may seem simplistic, it is linked to the concept of 'biotic resistance', which encompasses some complex aspects. There is a lack of consensus as to what constitutes it, with some researchers identifying it as "any negative influence on establishment" others take a more restricted view "limiting the term to describe repelling non-natives completely" (2007, p. 108). For the purpose of the present study, the term 'resistance' is used more broadly, as by Lockwood *et al.*, "to imply a reduction in establishment probability". Here, attention will be given to identifying connections that inhibited colonisation success of the focus species, albeit that the resistance may have been "place and time dependent" and not necessarily able to " limit population growth or the spread of a species after establishment" (2007, p. 109).

Whilst the concept of resistance is not central to the research, it is discussed in-so-much as when the spread of the focus species into some areas, has failed. Another facet of resistance relates to 'competition interactions', which are also referred to, but in very general terms. It was Elton (1958) who first suggested competitive interactions are a "frontline in the defence against invasion" (Lockwood *et al.*, 2007, p. 109), and that the more native species present in an ecological community, the greater number of roles (niches) exist within that community.

Therefore, the arrival and establishment of a non-native may be influenced by the use of resources it needs being utilised by existing native species in that habitat, thus reducing its chance of becoming established. The hypothesis won mathematical support in the simple *Lotka-Volterra* equations, which show that superior or equitable, already present, competitors will push out non-native species. Whilst non-natives may establish in habitats with few species, they will be likely to fail to establish in an adjacent habitat with more species. However, this does not mean all non-native species will be excluded due to an overlap in resources.

It may be that numerous native species will use only a portion of resources needed by the non-native to become established (Davis, Grime, & Thompson, 2000). So, it is not necessarily the number of species present, but rather, the way in which they function and utilise the resources available (Cowling, Mustart, Laurie, & Richards, 1994; Prieur-Richard, Lavorel, Grigulis, & dos Santos, 2000; Symstad, 2000). The argument as to whether it is species richness or species function that plays the greater role in invasibility is far from settled (Lockwood *et al.*, 2007). Research outcomes remain conjectural, as exploration is theoretical and relies heavily on modelling (Goodman, 1975; May, 1972; Pimm, 1979).

Although support for Elton's hypothesis has wavered, one must recall that experiments that do not support it, examined randomly assembled communities that were lacking stable interactions between native species prior to the arrival of a non-native competitor. Whereas in 'real time' communities, the behaviours of co-inhabitants link and persist, even stabilise and are not at all random (like those modelled), and "therefore, do not test how well a functioning real community might repel a non-native species (Lockwood *et al.*, 2007, p. 115).

In summing up on the subject of the 'invasibility', J.H. Brown (1989) proposed five 'Invasibility Rules' synonymous with biological invasion events. They are:

Rule 1: Isolated environments with a low diversity of native species tend to be differentially susceptible to invasion;

Rule 2: Species that are successful invaders tend to be native to continents and to extensive, non-isolated habitats within continents;

Rule 3: Successful invasion is enhanced by similarity in the physical environment between the source and target areas;

Rule 4: Invading exotics tend to be more successful when native species do not occupy similar niches; and

Rule 5: Species that inhabit disturbed environments and those with a history of close association with humans tend to be successful in invading man-modified habitats.

The rules proposed by Brown provide an excellent forum for discussion in regard to the colonisation 'stories' of the focus species. How they relate to each will be interpreted in the discussion in each of the case study chapters. However, the associated ecological concepts of 'resistance', 'mutualism' and 'facilitation' were considered beyond the scope of the present study and were not addressed in the case studies.

The final chapter from Lockwood *et al.* to be reviewed examines the ecological impact of invaders "from individuals, populations, and communities to ecosystems and effects on a global scale" (2007, p. 184) . The foremost concerns address problems related to 'genetic impacts', best described as "alterations to the gene pools of native species usually through hybridisation or introgression" (Krueger & May, 1991). Hybridisation refers to the interbreeding between distinct species (or sometimes genetically distinct populations).

The hybridized young are often sterile, effectively reducing native reproduction. If not sterile, they compete with native parent species and reduce reproductive rates and survival. Non-sterile hybrids can also 'backcross', resulting in 'introgression', an exchange of genes between species. This is especially problematic when 'hybrid vigor', aided by 'preferential backcrossing' of the hybrid young with the invasive parent species produces hybrids reproductively more vigorous than the native species, causing reproduction to be "increasingly tainted by genes from the invader".

Ultimately this can lead "to the loss of genetic integrity and the extinction of the native genotype one gene at a time" (Lockwood *et al.*, 2007, p.185). Several examples of hybridisation by an introduced species are cited, including the breeding between the Mallard Duck (*Anas platyrhynchos*) and several native duck species including: New Zealand Grey Duck (*A. superciliosa superciliosa*); Hawaiian duck (*A. wyvillana*); and Australian Black Duck (*A. superciliosa rogersi*).

In terms of the study area, whilst conducting fieldwork for a previous research project, hybridised offspring from Pacific Black duck and Mallard Duck were identified at a suburban wetland (in Gosnells, southeast of Perth). Other confirmed sightings of local hybrid offspring include crosses between native and non-native galahs (as reported in Chapter 1, page 5).

Other ecological issues that arise from the arrival of non-natives into local ecosystems, says Lockwood, are 'individual impacts', which according to Parker, Simberloff, Lonsdale, Goodell, and Wonham, (1999) include "changes in morphology, behaviour or demographic rates of natives in response to introduced predators or competitors" (in Lockwood *et al.*, 2007, p. 186). There are certainly examples of 'behavioural shift' in the focus species, as per the *Streptopelia* doves eating poultry feed and nesting in built structures, the White Ibis foraging at refuse sites, outside eating areas and in bins, and the Laughing Kookaburra allowing itself to be fed by people.

However, invasive species are most often investigated in relation to their effect at population level (Parker et al., 1999). This may be due to the "relative ease of measuring population numbers, distribution and age structure" (Lockwood *et al.*, 2007, p. 189). If left unchecked, the 'individual impacts' may potentially harm native species populations.

This is especially so in situations where a native species is endangered or rare, and the effects of the 'impacts' continue for consecutive years. A decline in population arises due to failed ecological mechanisms i.e. increased competition for resources, changes in the predator-prey scenario, or restriction of growth or reproduction due to loss of nest sites, eggs or hatchlings. An example given by Lockwood *et al.*, relates to two native parrot species in Eastern Australia, that complete with two invasive bird species for nest sites. The parrot's use of old tree hollows for nesting and reproduction has been hindered by habitat loss and too few nesting hollows. A solution has seen the introduction of artificial nesting boxes. However, since the installation of the nest boxes, there is already avid competition between Crimson Rosella (*Platycercus elegans*) and Eastern Rosella (*P. eximus*) for them. There is also further competition from "behaviourally aggressive invasive birds" (Lockwood *et al.*, 2007, p. 192), such as the Common Myna (*Acridotheres tristis*) and European Starling (*Sturnus vulgaris*). Both will drive out native species from the hollow to take possession of the site.

A similar scenario is developing within the study area, in relation to several endemic bird species, Short-billed Black Cockatoo (*Calyptorhynchus latirostris*), or Carnaby's Cockatoo, Long-billed Black Cockatoo (*C. baudinii*), or Baudin's Cockatoo, and Red-tailed Black Cockatoo (*C. banksii*). All are listed as endangered due to significant population declines attributed to habitat loss. Each utilise hollows formed in very old Eucalyptus trees, which have been extensively cleared, resulting in a shortage of food and nesting hollows. Increasingly, the hollows that remain are being occupied by other abundant species, such as Pink and Grey Galah (*Cacatua roseicapilla*) and Western Ringneck (*Barnadius zonarius*). The Laughing Kookaburra is also a hollow nesting species (preferring hollows situated in a tall tree, predominantly Eucalypts). The potential implications of which, are investigated later in the thesis.

The impact of predation is also often the subject of enquiry in relation to biological invasion scenarios "probably because of the often-devastating effects of invasive predators on island systems where the native fauna are evolutionary naïve to their effects" (2007, p. 192). However, within the scope of the present study, the impact of predation *upon* the focus species is not substantial enough to merit detailed discussion. Whilst there are some issues related to predation *by* the focus species, where the Australian White Ibis and Laughing Kookaburra are concerned, discussion is limited to general terms.

Returning now to Williamson, who authored the text *Biological Invasions* (1996) which included in it the '*Tens Rule*' put forward earlier by Lockwood *et al.* Williamson believes "that it is unusual for the course of a particular invasion to be predictable" (1996, p. 31).

Whilst he considers it unlikely a specific model can accurately predict the success of an invading species, he is supportive of adopting a statistical approach to the study of biological invasion phenomena as a means of characterising possible outcomes. In response to this belief, the '*Tens Rule*' was fashioned, in conjunction with Holdgate (1986) and Williamson and Brown (1986), in an attempt to quantify the extent of invaders that establish and become pests:

> A useful rule of thumb is the tens rule, that 10% of feral (or introduced) invaders, invasive species living outside captivity in any sense, become established, and 10% of those established become pests (Williamson, 1996, p. 33).

The rule, says Williamson, is useful as a measure, or guide to the study of phenomena with many variations and exceptions, and, as the rule often holds, is an important reference point in the study of biological invasion events. Although, he warns that, as with other statistical rules, "it needs to be interpreted with care" (1996, p.33). Although it is not without merit, the rule is not applied in relation to the focus species, although a comprehensive list of avian species introduced into Western Australia, as per Long (1988), is included in the Appendices (Appendix 8).

The text also discussed several other ideas, including the "relationship of invasion success to the abundance of a species in its native range, or the size of the range, or both" (1996, p.67). However, whilst "the evidence is rather against wide-ranging species being generalists or having wide niches and there is no good evidence that dispersal is important in establishment" (1996, p.68), the ideas were not held central to the present study.

Another concept proposed by Williamson is 'climatic matching', whereby the range of all species extends to "certain climates but not in others" (1996, p.69). He cites several examples and summaries related to the concept, and identifies it as "a factor that ought to be of overriding importance and yet is on the whole a rather weak indicator or predictor" (1996, p.71). This view concurs with the conclusions drawn from the present study, which indicate that 'climate matching' between the source areas the focus species originated from, and the patterns of settlement they established in the study area, was not a major determinant.

The text also discusses the concepts of 'vacant niche' and 'ancestral habitat'. What merit, asks Williamson, is there in thinking that "successful invaders occupy a vacant or empty niche, while unsuccessful ones are excluded because their niches are already occupied" (1996, pp.71-72). He argues that this approach is "at once helpful and confusing" (1996, p.72). Although ecologists find the concept of 'niche' helpful, the term becomes confused as "different ecologists, and indeed sometimes the same ecologists on different occasions, use the term niche in different ways" (1996, p.72).

For example, it can be referenced a number of ways, as ‘habitat niche’, ‘functional niche’, ‘trophic niche’ or ‘resource niche’. Therefore, he advises, be cautious in applying this model as an interpretative tool of biological invasion phenomena. Again, whilst reference is made to possible ‘niche overlap’ and ‘niche reduction’ in relation to the Laughing Kookaburra (in relation to competition for food and nesting resources with native species in conservation areas), these principally ecological concepts are not key themes investigated in this primarily geographical study.

The ideas presented by Williamson contribute significantly to the study of invasion biology. Including a conceptual framework that lists points related to a four-phase invasion process. It too has been adapted to the present study and discusses the relevance or lack of, the concepts presented, to the present study (Table 2.1).

Also consulted was *Nature Out of Place* (Van Driesche & Van Driesche, 2000) which effectively summarises many of the ideas reiterated here:

> In general, non-native species are more likely to establish if they invade habitats with lowered biotic resistance, encounter prey with poorly developed mechanisms of self-defense, or invade habitats unaccompanied by their specialized natural enemies or when their invasion is facilitated by earlier invaders (Van Driesche & Van Driesche, 2000, p. 99).

Several other noteworthy texts within the discipline were also studied. Whilst not reviewed individually, they warrant listing as each contributed toward the preparedness sought in formulating a rigorous theoretical framework. They include: *The Ecology of Pests: some Australian Case Histories* (Kitching and Jones, 1981); *The Ecology of Exotic Animals and Plants* (Kitching, 1986); *Ecology of Biological Invasions: An Australian Perspective* (Groves & Burdon, 1986); *Biological Invasions: A Global Perspective* (Drake *et al.*, 1989); and *Biogeography of Mediterranean invasion* (Groves & Di Castri, 1991).

This closes discussion on concepts related to the study of invasion biology, or invasion ecology, as it sometime referred. Discussion now moves to concepts that convey ‘Population Ecology’ and ‘Population Dynamics’ principles pertinent to the research.

Table 2.1: Conceptual framework of Williamson (1996) in relation to the Present Study
(Adapted from Williamson, 1996)

Stage of Invasion Process	Conceptual Framework Point Williamson (1996)	Relevance to Present Study
Arrival and Establishment	0. Whilst the majority of foreign arrivals result from human importation, natural arrivals are also of interest.	Focus species reached study area through acclimatisation (deliberate release), aviculture (accidental release) and immigration.
	1. Only a limited number of taxa are successful invaders, with the majority failing.	Focus species represent only a percentage of avian introductions into study area.
	2. An important variable is propagule (or invasion) pressure, so therefore invasion often occurs in accessible habitats by transportable species.	Focus species are highly mobile (transportable) and have invaded accessible habitats in both urban and rural areas.
	3. Whilst some ecological communities are more invasible than others, all communities are invasible.	Study area intensely modified. Sightings concentrated in settled, urban areas. However, irruptions of invaders have also occurred inside conservation areas.
	4. Invasion success is unpredictable due to the complexity of factors involved i.e. rate of natural increase, abundance in native habitat, climatic and habitat matching, vacant niches and taxonomic isolation.	The present study will consider Climatic Matching in relation to the focus species successful adaptation to the adopted landscape.
Spread	5. Spread can occur at any speed, in any direction, with analysed cases occurring as predicted by estimates or the intrinsic rate of natural increase and the diffusion coefficient, or faster.	Spatial and temporal maps support this. Predictive *Spatial Statistics* related to the focus species indicate possible direction of future spread.
Equilibrium and effects	6. The majority of invaders have only minor consequences upon areas invaded.	Evidentiary support suggests few of the focus species have had a major economic, social or ecological impact on study area.
	7. Major consequences can be summarised as effects, including ecosystem restructuring, depressed populations, individual extinctions and mechanisms, such as competition; enemies (vertical food chain processes); swamping (horizontal food chain processes) and amensalism (one organism is unaffected whereas another is impacted negatively).	Focus species are 'generalists' that have adapted to highly modified habitats. To date there is no record of them depressing local populations to the point of extinction. There is evidence of amensalism in association focus species that nest in hollows.
	8. Genetic factors play a role in determining invasion success, both at time of initial invasion and resulting evolutionary change following invasion.	The study is not an investigation of genetic or evolutionary factors.
Implications	9. Invasions inform about ecological community structure and the strength of interactions between inhabitants (and vice versa).	The study investigates inter-relationships between the focus species and areas colonised, along with plausible implications for local species.
	10. Studies of biological invasion add relevance to matters related to the introduction of new genotypes, the release of genetically engineered organisms, the consequences and success of biological control.	Central to the aims of the research is the belief that it will augment existing knowledge of biological invasion events and processes.

2.1.2 Population Ecology and Population Dynamics:

Whilst concepts related to the study of invasion biology are key elements of the present study, the disciplines of population ecology and population dynamics were also investigated. In the main, queries from within these disciplines are concerned with the following: Why do particular species live where they do? Why do population densities vary? What determines population density? Is population density regulated? If so, how is it regulated? However, as this is principally a geographic study, concerned with the 'spatial' and 'temporal' aspects of the population distributions, rather than the densities of the populations *per se*, in effect, the only question that remains to be answered in relation to these disciplines is 'Why do species live where they do?

Central to the study is the enquiry as to how the ecology of each of the focus species, i.e. feeding, roosting and breeding regimes, impacts on colonisation and dispersal. This is especially pertinent if a species settles an area of modified habitat which lacks the usual barriers to spread, i.e. resource competition. In such a scenario, the boundaries of the ecological 'niche' that might normally constrain a species have been removed, thus reducing natural processes. At this point, discussion diverges into ecological concepts which are addressed later in the chapter.

Up to this point, discussion of the literature has focused on identifying factors that influence the potential success or failure of non-native species to establish a population in an area to which they have been introduced. It has been identified that these vary between species, and are dependent on several factors.

Initially, the invading population may be low and its current range is able to provide sufficient resources, negating the need to travel and disperse. Or alternately, it may not be well suited to the new environment and persists in very low numbers within the colonised area (Shigesada & Kawasaki, 1997). This delay in range expansion suggests a 'genetic adjustment' is needed in order to produce favourable offspring. This can be the case up until the population has recovered sufficiently to breed, at which time "range expansion becomes evident when the population reaches a sufficiently high level" (1997, p.28). This can be seen most clearly in the Spotted Dove, which, subsequent to colonisation, experienced steady declines in sightings in rural areas, and increases in urban sighting for each period.

Once established, the population moves into an 'expansion' phase, determined by the "life history characteristics of each species" (1997, p.28). Following on, the population will then move into a 'saturation' phase. When the population density increases constantly in occupied territories, there is a continued push into new territories. The duration of each phase varies between species as it is dependent on a number of factors: ecological suitability of the species to the new habitat; dispersal ability of the invader; invasibility of the habitat.

At the ‘saturation’ stage in the invasion process, as a general rule, the species can be said to be ‘identifiable and interactive’ with native species at different sites. Range expansion is therefore necessary to secure resources for feeding, roosting and breeding away from the parent, population. The spatial patterns of range expansion can be depicted in many different ways. Below are three types of range expansion diagrams that show marked differences (as per Shigesada & Kawasaki, 1997) (Figure 2.2).

The conclusions drawn from the present study however, suggest other than the need for a ‘genetic adjustment’ to produce ‘favourable offspring’ in the colonised landscape, colonisation success and the extent of dispersal is i.e. range expansion of the focus species may also be dependent on it being able to incorporate ‘ecological adjustments’ into its feeding, or nesting, or roosting regime to survive, and its adaptability in developing productive colonisation strategies to sustain, and grow its population.

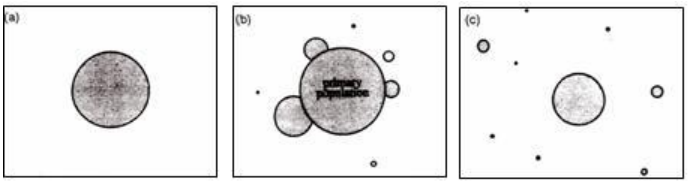


Figure 2.2: Spatial Patterns in Range Expansion
(Shigesada & Kawasaki, 1997)
(Exception to copyright: Section ss 40, 103C for Research or Study)

According to the models shown above, a species may (a) increase its range by expanding outward from the periphery of the primary population; (b) expand its primary population from the periphery, and simultaneously establish satellite colonies by means of long-distance dispersal, then settle reasonably close to the primary population (as both the primary and satellite populations expand, their ranges will combine at some point); or (c) individuals will scatter widely from the parent population and their new territories will remain in isolation from the parent population for a prolonged period (Shigesada & Kawasaki, 1997, p. 29).

In their investigations of range expansion modelling, Lockwood *et al.* presented somewhat of a different approach, suggesting the simplest way to envisage ‘spread’ was to see it as a series of concentric circles radiating outward from the initial point of introduction. Each circle representing the amount of space across which the invader has moved in a finite period of time. Although simplistic, the method is often surprisingly accurate (it is the method Elton adopted in his pioneering text on invasion biology).

Other than the examples given here, there are a number of other spatial-temporal models that can be applied to modelling range expansion say Lockwood *et al.* The outcomes of which are an aid to planning for wildlife managers and conservation stakeholders. However, these are not adopted in the present study and not presented for further discussion. For closer examination of the models Lockwood *et al.* (2007, p. 143 - 156) is recommended.

Rather, arising from the methodology developed for the present study, the depiction of the spread i.e. range expansion of the focus species took a unique form. The chronological dispersal of each of the focus species throughout the study area, subsequent to colonisation, was depicted by colour coded point data for each record, for each stage (Era A, Era B, and Era C), imposed over a base map of the study area. Expressed in this way, the geographical extent of sightings could be identified, as well as associations, or lack of, between the data for each stage. The data were also used to derive spatial autocorrelation statistics (refer Chapter 3, page 56).

The range expansion of a species is driven by its 'dispersal', a term which can be used to either describe "the movement an individual animal makes from its place of birth to the place where it reproduces Sinclair, Fryxell & Caughley (Eds) (2006, p. 90); or "the movement of individuals into or out of the population area" (Emmel, 1973, p. 71). Used in these contexts, it usually takes three distinct forms: immigration, emigration and migration. However, in its most generalised form, the term is used to define "movements that, at the population level have no fixed direction or distance" (Newton, 2003, p. 471). It is within this context that the term is applied within the present study, to imply the movement of the species across the landscape, or the extent of populations' within the study area.

Whilst it can refer to "simultaneously an ecological process affecting distributions and a genetic process affecting geographic differentiation" (Krebs, 1985, p. 41), the mixing of individuals from different localities will not always alter the distribution pattern of a species. Though, it may "lead to range extension and to colonisation of new areas outside the existing range" (Newton, 2003, p. 471). The real benefit of dispersal is it promotes gene exchange between unrelated individuals and helps reduce in-breeding within a population. The act of dispersing "allows birds to respond rapidly to local conditions" (Newton, 2003, p. 472) and assists them in relocating away from a habitat that is unfavourable, i.e. either under-resourced or over-crowded. It may allow a species to maintain a presence in an area where the population is in decline, or assist in it reoccupying previously vacated habitat.

It can also result in numerous outcomes: as dispersers may colonise vacant habitat in harsh, variable environments; take multiple chances at winning occupied sites in healthy, stable environments; or regulate rates of inbreeding and outbreeding. Often it is advantageous to parents at the cost of high mortality amongst offspring (Horn, 1984, p. 54). Paradoxically, it can allow competitors to coexist within a changing spatial mosaic, or bring them into conflict. It can help prey escape predators or bring more predators into a prey population, i.e. such as the Australian White Ibis, and the Laughing Kookaburra, which prey on a range of invertebrate species within the study area. However it is viewed though, dispersal is a crucial driver in ecosystem function, an ecological process that impacts upon population distribution (and density), as well as the genetic structure of populations.

Despite the mobility of birds, the assumption they can disperse to anywhere, even within their geographical range, is incorrect. Many bird species, as well as some mammals and reptiles (Switzer, 1993) "are faithful to their natal and breeding site or group" (Greenwood, 1980, p. 1140). In most species, one sex is more philopatric, i.e. it remains in, or returns to its birthplace more than the other. In birds it has been found that usually females disperse more than males (Greenwood, 1980).

The term 'site fidelity' (as defined by Gauthreaux, 1982), applies to individuals within a species that display a distinct "faithfulness to a site or group" (Greenwood, 1980, p. 1140). In this sense, individuals, that may have initially dispersed away from the natal site, once having bred in a location, will return to and reuse that occupied site subsequently and "breed in the same area in successive years". Although many species are philopatric, usually "only a proportion of individuals of any species is faithful to one locality" (Greenwood, 1980, p. 1140). The remainder of the population will disperse under their own auspices, or as a result of being forced out of an area, or due to environmental determinants.

The concept of site fidelity is not to be confused with 'natal philopatry', whereby "offspring remain at their natal area and share the home range or territory with their parents" (Goodenough, McGuire, & Jakob, 2010, p. 234), and which is contrasted to 'natal dispersal', "the movement between the natal area or social group and the area or social group where breeding first takes place". All of these behavioural and environmental restraints limit their dispersal distances and as a consequence, the gene flows through populations.

The extent of dispersal however, may not always alter the extent of a species' geographical range, as at times it may be unable to overcome a barrier (or multiple barriers) to spread. Whilst it may not always change the overall distribution of a species, it does however influence patterns of abundance and distribution within the range, i.e. 'dispersion'.

The patterns of dispersion in a population are linked to the availability, or scarcity of resources within the species established range. Depending on which, the distribution will usually display one of three generalised patterns: (a) random; (b) uniform; or (c) clumped (Emmel, 1973) (Figure 2.3). Although the classifications generated in the *ArcView 9.2* autocorrelation statistics differ slightly from these, being: (i) random; (i) clustered; or (iii) dispersed (refer Chapter 3, pages 58-59).

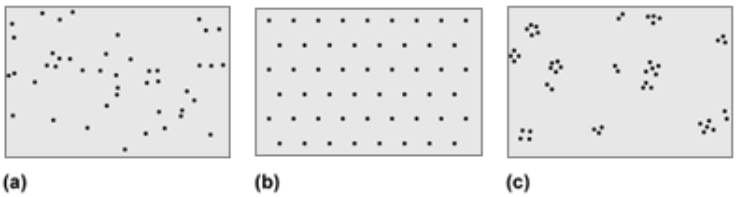


Figure 2.3: Basic Patterns of Dispersion of Individuals in a Population
(Random, Uniform and Clumped) (Emmel, 1973)

Random dispersion describes a pattern of "individuals scattered over an area without any regularity or any degree of affinity for each other" (Emmel, 1973, p. 64). It is rare in nature, as it demands an environment uniform in its make-up. If resources were evenly distributed throughout the population's range, individuals would neither amass to take advantage of a resource, nor repel others to protect it. Just as "we usually find non-random dispersion of resources in nature, organisms are almost never random in distribution" (1973, p. 64).

Uniform dispersion has more regularity than a random dispersion but still does not allow for the aggregation of individuals within a population. Whilst not infrequent in nature, uniform distribution usually occurs when competition for a resource is extreme or "positive antagonism promotes even spacing" (1973, p. 65). It is more common amongst plants, although can be found in some seabird colonies. When actively defended by a species, the defended habitat is defined as a territory.

Clumped dispersion, also referred to as 'aggregate dispersion' is the most common pattern, and refers to the non-random, irregular distribution of individuals in a population. The extent of the pattern may differ and it may only be present at certain stages in the lifecycle or times of the year. The clumps (or aggregates) may be scattered either randomly or uniformly throughout the range.

This depends on how sessile the species is, how resources are distributed and the level of social interaction of sub-groups within the population. In essence, it is a response to individuals seeking out optimal habitats (temperature, light, minerals, water etc.). Its most negative aspect is that it "almost inevitably *increases competition* for light, nutrients, food or space" (1973, p. 66).

This is especially so in relation to birds, with Lack (1954) concluding that birds are not dispersed either randomly or uniformly throughout their environment, particularly when breeding. Rather they breed at the highest density where food, especially food for the young, is plentiful: a phenomenon that Lack describes as 'dispersion'.

This state, he says, is bought about mainly by the behaviour of first time breeders, which tend to settle in greater number in the more favourable habitats. This is only up to a point, after which they will relocate to "a type of habitat less favourable except in being less crowded" (Lack, 1966, p. 299). In short, Lack's main idea is:

> …that, while populations of birds and other animals are ultimately limited by the availability of food, this limit, with resultant overpopulation and starvation, is not normally reached in nature, because dispersion through behaviour keeps numbers near to the 'optimum' and below the level where 'overfishing' might develop (Lack, 1966, p. 300).

However, within the present study, the term 'dispersion' specifically refers to the internal distributions of a population, within its established geographic range.

If further insights into these disciplines are sought, there are a number of appropriate texts and articles that can be consulted, including *The Distribution and Abundance of Animals* (Andrewartha & Birch, 1954), *Rate of Increase* (Caughley & Birch, 1971), *Two Paradigms of Population Regulation* (Krebs, 1995), *Population Growth Rate and its Determinants: An Overview* (Sibley & Hone, 2002), and *Graeme Caughley and the fundamentals of population ecology: a personal view* (Sibley & Hone, 2002). Between them, these authors cover, most, if not all, the main tenets associated with these disciplines.

This concludes the examination of these topics. Discussion now moves to the investigation of some fundamental ecological concepts. It is not intended as a comprehensive review of the discipline, but to illustrate familiarity with them, in relation to the research.

2.1.3 Ecology:

Since its inception, the study of ecology has attracted intensive and diverse theoretical discussion. Essentially, ecology is the study of the "scheme of relationships among factors and processes influencing the distribution and abundance of a species" (Wiens, 1989, p. 93). This extends to a complex interplay of factors including environmental features (climate, habitat, food, area occupied); disturbance; individualistic species-specific responses (behaviour, physiology, morphology, habitat selection, dispersal; intraspecific interactions); predation; competition, mutualism and parasitism.

As with the study of biological invasion phenomena, the discipline of ecology owes much to Charles S. Elton, one of the first proponents of the "notion of a functioning ecosystem" (Kikkawa & Anderson, 1986, p. 8): a concept central to his book *Animal Ecology* (1927). In it he raises the query as to how animals regulate their population to avoid over-abundance or extinction, proposing that:

> The manner in which animals are organised into communities with food-cycles and food-chains to some extent answers the question. As a result of the existence of progressive food-chains, all species except those at the end of chain are preyed upon by some other animals (Elton, 1927, p. 117).

In the text, Elton also noted that "fewer animals occupied the upper levels of any chain" (quoted in Kikkawa & Anderson, 1986). When depicted graphically, i.e. size class against number of individuals, it showed a 'pyramid of numbers', displaying the fit of a species to a particular role, or 'niche' in the ecological community to which it belonged. The concept was seized upon by others and generated erstwhile theoretical discussion. It was developed to some extent by H.T. Odum his book *Environment, Power and Society*, (1971).

The convictions of Elton that the controlling processes in animal populations were caused by biotic interactions within the network of species within a community were shared by many. However, it was Elton who kept the ideas simple and identified five main biotic relationships; (i) intraspecific competition, (ii) interspecific competition, (iii) herbivore-plant relations, (iv) predator-prey relations, and (v) parasite-host relations (Elton & Miller, 1954, quoted in Kikkawa and Anderson, p. 12), which encapsulates the basic tenets of the study of ecology.

Just as C.S. Elton is credited with being an initial exponent of the 'niche' and its related concepts, the idea that "there were rules to govern how communities might be assembled" (Fox, 1999, p. 23) can be attributed to J.M. Diamond (1975). As after collecting observational data on bird species distributions around New Guinea, he drafted 'incidence functions' for each to identify their ecological 'role' or 'strategy'. The data, presented as a series of graphs depicted resource utilisation against resource availability, and were aptly titled 'resource utilisation curves'.

The concept was developed further, and produced a hypothesis proposing it was the "assembly rules predicting which species were able to co-exist" (1999, p. 23) with combinations made up of species that were either 'allowed', or 'forbidden' in the assembly.

Again, the work of R.H. MacArthur and E.O. Wilson (1967), was influential, specifically in relation to their '*Equilibrium Theory of Island Biogeography*' paradigm. Whilst this model was probably the strongest influence on Diamond's thinking, his views expanded to include niche theory and the pre-eminence of interspecific competition. These ideas, and those of his co-author Martin Cody (1975), greatly promoted the study of ecology.

However, Diamond's ideas were met with sound debate in the ensuing decades. In particular, there was opposition to the centrality of interspecific competition in the hypothesis. The detractors argued that the observed patterns could be due as equally to chance events, as a result of stochastic, rather than deterministic processes (Connor & Simberloff, 1979). Both methodological and statistical disparities were aired and argued.

The most limiting aspect of studying ecological communities within the 'Assembly Rules' paradigm, was the large amount of data collection it demanded. In response, as a result a simpler rule was proposed by which species from the same genus; or from taxonomically related groups, or from 'guilds' were viewed as a 'functional group' to encompass all these classifications (Fox, 1999, p. 31).This resource-based rule made the simple assumption that the usual distribution of resources would have approximately the same amount of available to each trophic level, of which there are three groups: insectivore; omnivore and herbivore. The 'Guild Assembly Rule' necessitated viewing species as belonging to a 'functional group', rather than as individual species within an assemblage.

It has since been widely tested (Fox, 1987; Fox & Brown, 1993; Kelt, Taper, & Meserve, 1995) across a "great breadth of biogeographical regions, taxonomic groups, vegetation types and spatial scales" (Fox, 1999, p. 40). Results show, that based on resource availability, resource partitioning and interspecific competition, it is a valid alternative hypothesis to that proposed by Diamond (1975), and is now accepted ecological theory.

Another principle central to the study of ecology is 'territoriality'. It is important as it can impact on the owner's reproductive output and, its survival *per se*. Territoriality is closely linked to 'competition', in that, if "all resources were superabundant then there would be little point in birds defending them" (Perrins & Birkhead, 1983, p. 10).

However, as resources are limited the protection of them is crucial, whether it is food, breeding sites, or mates. Or in fact, just space itself. As, more space between neighbours reduces predation and lowers intra-specific and inter-specific interference. Several 'functional classes' of avian territories have been identified (Hinde, 1956). These were later adapted by Perrins and Birkhead (1983) (Table 2.2). These categorisations will be related to each of the focus species in the discussion within the case studies.

Table 2.2: Functional classifications of avian territories
(Hinde, 1956 in Perrins & Birkhead, 1983)

Functional Classification of Avian Territories (as per Hinde 1956)	
Type	**Description**
Type A	Large defended area, all activities (roosting, courtship, mating, nesting and feeding). Classic 'all-purpose' territory. Can be occupied by a pair or a group of birds. Marked relationship between territory size and bird size, as larger birds need more food in absolute terms.
Type B	Large defended area within which all breeding activities occur but which is not the primary source of food. Relatively rare.
Type C	A small defended area around nest. Some hole-nesting and many colonial species utilise this restricted type of territory.
Type D	A small defended pairing or mating territory.
Type E	Defended roosting positions and shelters. Many socially roosting birds defend sleeping positions.
Type F	Non-breeding territories. Some species defend feeding areas in winter or during breeding season away from the breeding area.

As much as there are benefits to territoriality, there are costs associated with territorial defence. Threat displays and fighting off interlopers is time consuming, expends energy and involves risk taking that could result in injury or death. It is reasonable therefore to assume that a species would only defend a territory if the benefits outweighed the costs and aided survival and reproduction. The concept of 'economic defendability' was first proposed by Brown (1964) and later revised (1969).

By way of explanation, as the size of a defended territory increases, so do the costs and benefits. The benefits (i.e. amount of food) initially increases but tapers off once it exceeds the needs of the bird. The costs (i.e. energetic) would continue to increase. Only the territory between *A* and *B* should be defended, with the optimum territory size at *X*. where the difference between the costs and benefits is at its maximum. Territory between A and B should be defended, optimum territory size at X where difference between costs and benefits is greatest (Perrins & Birkhead, 1983) (Figure 2.4).

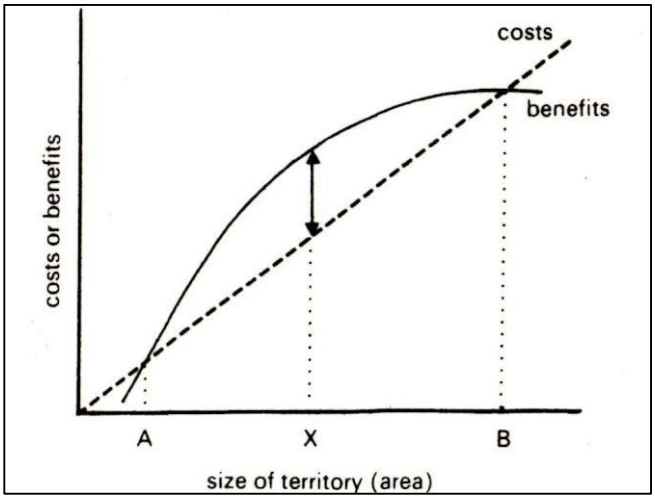


Figure 2.4: Brown's ***Economic Defendability Model***
(in Perrins & Birkhead, 1983)

In his classification of avian territories, Hinde (1956) referenced 'Type *A*' species in relation to their body size, i.e. the larger the bird the larger the territory. The idea was seized upon and developed further by T.W. Schoener (1968b) who found that "territory size was directly proportional to the bird's body weight, i.e. larger species defended larger areas" (Perrins & Birkhead, 1983, p. 12) (Figure 2.5).

Different relationships exist for predators and herbivores (Schoener 1968(b) in Perrins & Birkhead, 1983). A second approach that compared individuals of the same species doing different things lent further support to the idea. Another (Stenger, 1958) found that when food was abundant, the size of the territory reduced.

Should body size differences "constitute the causal basis for the utilization of different types of resources by different species" (Tokeshi, 1999, p. 318), then it can be said that body size is a determining factor in defining the ecological niche of the species. In this case, taxa with larger, wide-ranging body sizes will probably achieve greater species richness than smaller sized species with narrower niches. Conversely, if resources occur in limited and discrete size ranges and differential use is prescribed by body size, the latter becomes the more significant determinant. Here discussion moves into resource partitioning, which for more detailed discussion refer to articles presented by T.W. Schoener (1968a, 1974).

Although the present study is not concerned with the population densities of the focus species specifically, the density of a population is a major determinant of territory size. Liken it if you will says J.S. Huxley (1934), to a series of rubber discs which, "as population density increased the discs were compressed, up to a point beyond which they could not be compressed further" (in Perrins & Birkhead, 1983, p. 20). Basically, as population density increases, territory size decreases. However, there is a minimum territory size, with anything smaller than that unable to provide sufficient ecological resources to support an individual.

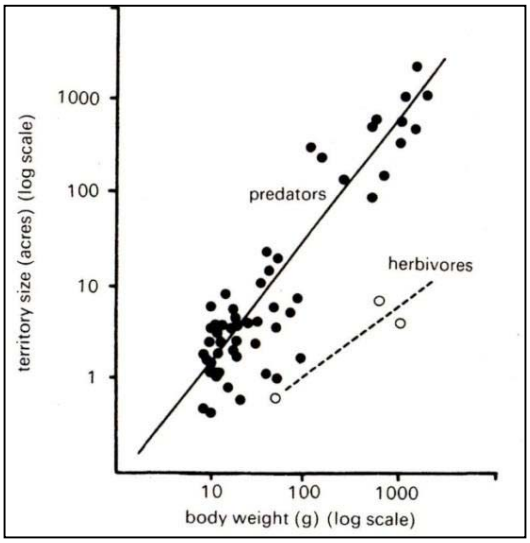


Figure 2.5: Relationship between territory size and body size among birds
(Each point represents a different species) (Schoener 1968 in Perrins & Birkhead, 1983)

As to whether birds live solitarily or socially is determined foremost by the spatial distribution of resources: i.e. food and nest sites as well as exposure to predation. If resources are closely clustered, the birds that utilise them will feed in flocks and breed in colonies. Whereas, when resources are evenly spaced, dispersion is uniform with individuals, pairs or families defending a territory large enough to sustain them. To minimise predation, populations are likely to be spaced out, or in the case of colonial nesters, grouped to aid joint defence against nest predators. The actual act of breeding is set to coincide with having "young at the nest at the time food is most abundant" (Perrins & Birkhead, 1983, p. 73).

The ecological requirements necessary for a species to survive are closely tied to the ecological 'niche' it occupies, a concept touched upon briefly in earlier discussions. Essentially, the term defines a species "place in the biotic environment, *its relation to food and enemies*" (Elton, 1927, p. 64). It is not something that can be seen, nor measured, "or at least not more than a few features of it" (Perrins & Birkhead, 1983, p. 138). The niche occupied by a species is not determined simply by the type of food it consumes, but by the amenity it requires: it must provide for food, foraging or hunting aids, and suitable nest sites and materials. Birds defend territories that contain the required resources.

When species vie for resources within a territory against conspecifics (individuals of the same species), competition is termed ‘intraspecific’; when it is against individuals of another species it is termed ‘interspecific’. When species with identical niches occupy the same space, or territory, there are a number of possible outcomes: (a) they may co-exist without ill-effects if the resource is temporarily unlimited (the general assumptions in ecology in discussions about competition between species implies all resources are limited). If the resource is limited, “co-existence is impossible by definition” (1983, p. 139) (Figure 2.6).

Otherwise: (b) one species may be more efficient at harvesting the resource in which case, the less efficient species will either change its niche, or become extinct. Although, it is unlikely one would change its niche completely, and the other not change its niche at all, but rather, each will become more efficient than the other in a part of the niche. So, as with most co-existing species: (c) both will alter their niche (Figure 2.7).

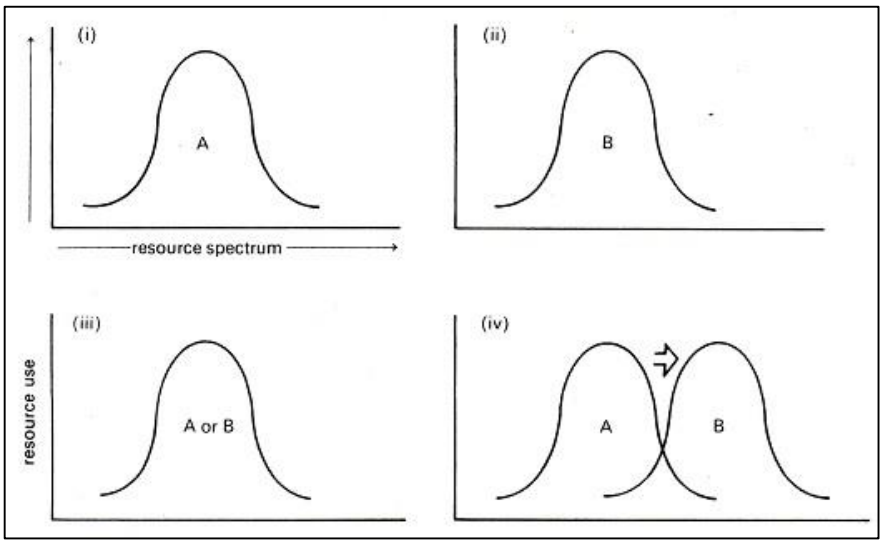


Figure 2.6: Effects of Competition (a and b)
When there is competition between two species with identical resource requirements: (i) and (ii). Either one species will die out (iii) or it will shift its niche to reduce competition, show here (iv) by species *B* shifting its niche (Perrins & Birkhead, 1983, p. 140)
(Exception to copyright: Section ss 40, 103C for Research or Study)

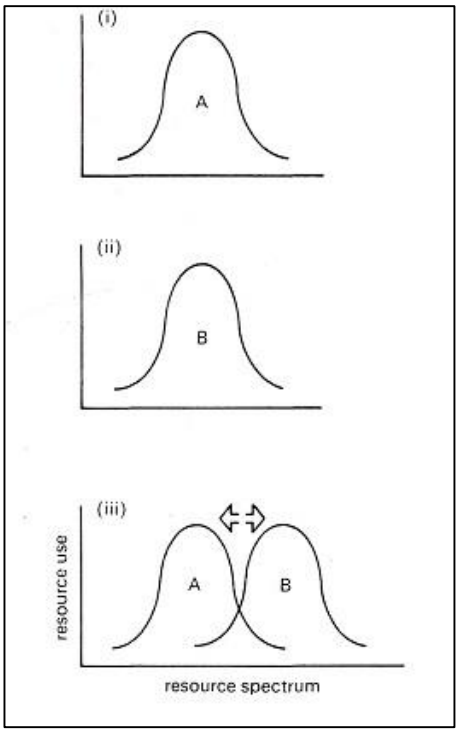


Figure 2.7 Effects of Competition (c)
When there is competition between two species with identical resource requirements: (i and ii). Here (iii) both species *A* and *B* shift their niches (Perrins & Birkhead, 1983, p. 141)

The reason it was easier for two species to coexist in a mosaic than three or more species was explored by Robert MacArthur (1972), who proposed that when competition is limited to just two species, one can alter its niche. Whereas when there are three or more, the niches overlap, making it difficult for the species in the middle to retain its place. This causes a narrowing of the niche or reduction in population due to resource limitations. Survival is possible though, if a species can access its 'fundamental niche', i.e. what it would occupy if competitors were absent, or 'realized niche', what it can occupy when competitors are present. It is not easy to differentiate between them, and both may include "some form of interaction between intra-and interspecific competition" (Perrins & Birkhead, 1983, p. 143).

Whilst it is agreed there is overlap in competition for ecological resources, it is a complex matter that lacks consensus amongst ecologists. Some disdain it as a theoretical construct with little relevance, if any, in nature (Tokeshi, 1999, p. 150). Inextricably linked to 'competition' is the concept of 'competitive exclusion', which moves discussion deeper into ecological concepts and away from the geographic principles of the present study, so will not be dealt with here. For a detailed account of such, the reader may refer to the relevant section of W. Arthur's, *The Niche in Competition and Evolution* (1987, p. 17).

The final concept investigated, albeit briefly, is 'predation'. Birds are highly susceptible to being preyed upon. Many of the behaviours they display are adaptations to reduce the impact of predation on localised populations. However, in terms of the present study, discussion related to the concept is limited to predation *by* the focus species (the taking of eggs and young of other birds, and of invertebrates, amphibians and reptiles).

Predation affects community structure "by depressing populations of competitors beneath resource-limitation levels" (Wiens, 1989, p. 95). It can alter the outcomes of competitive interactions and, in some instances, eliminate them entirely. Predation has been identified as a major contributing factor toward bird extinctions on islands (up to 90% according to Greenway 1967).

Other key indicators of species extinctions (especially on islands) are habitat change, and competition from introduced species. Island biotas in particular, have been described as displaying "innate weaknesses… against alien competitors or predators" (1999, p. 359). At which point, it is timely to recall that the study area is island like. It has also been subjected to extensive habitat modification, and supports established populations of many introduced plants and animals, including birds. These are reasons enough to ensure continued vigilance in the monitoring and assessment of the state of wildlife populations in Southwestern Australia.

This concludes discussion on fundamental ecological concepts. The basic tenets of island biogeography are now presented.

2.1.4 Island Biogeography:

The study of this discipline commences with examination of the text, *The Theory of Island Biogeography* (1967), by Robert MacArthur and Edward Wilson. The text revolutionised research in the field of biogeography. It was immediately criticised for eschewing conventional wisdoms, and the ideas postulated met erstwhile challenges, not all of which have been resolved. Central to the text was the 'Equilibrium Theory of Island Biogeography' (ETIB) which sought to "provide a stimulating and productive means of identifying important questions about the dynamics of species richness" (Heaney, 2000, p. 59). The paradigm has been widely adopted despite its simplicity: two variable processes - colonisation and extinction - with few discrete predictions generated.

Theoretically, ETIB challenged the 'static theory' of island biogeography (refer Dexter, 1978), which was prevalent at the time of the book's publication. The hypothesis of static theory proposed that "insular community structure was fixed in ecological time, resulting from unique immigration and extinction events" (Lomolino, 1999, p. 272). Put simply, it implied that an immigrating species either made it to an island, or did not: on arrival it found sufficient and perpetual resources for survival, or conversely, failed to establish a population.

ETIB, on the other hand, proposed that "community structure was dynamic in ecological time, resulting from recurrent immigrations and extinctions" (1999, p. 272). That is, as an island filled to capacity with species, immigration rates declined and the extinction rate increased "until an equilibrium number of species was attained". Thus, species richness remained constant whilst species composition changed as new species replaced extinct species.

In short, the ETIB paradigm postulated that species diversity on an island is relative to its size and isolation, and that a dynamic equilibrium exists between immigration and extinction. Whilst the number of species may stay the same, "the detailed composition of an island's fauna and flora might vary considerably over the longer term (Gentilli, 1979, p. 100).

Although it was initially lauded as "a great conceptual advance over the theories that dominated island biogeography in the mid-20th century" (Lomolino, 2000, p. 2), ETIB has since been criticised for being fundamentally flawed. There are, says Lomolino, three main limitations to the model. Firstly, as the spatial and temporal scale of recent studies has broadened, it has become evident that many systems are not only dynamic in species composition, but "seldom attain an equilibrium number of species" (2000, p. 3). Such systems, whilst displaying evidence of speciation, may have faced geological or climatic events, or anthropogenic disturbances that modified the species pool or immigration and extinction rates prior to the equilibrium of species being attained.

Secondly, the theory operates on the assumption that in and around archipelagos "insular habitats and immigration filters (intervening landscapes or seascapes) are homogenous" (2000, p. 3). To the contrary, says Lomolino, variation in insular species composition and species richness within such areas can be due to predictable variation in both environmental conditions and habitat amongst islands: i.e. bigger islands, increased habitat diversity. Rather, differences in community structure in such areas can easily be the result of immigration filters: i.e. bodies of water with or without strong currents, or landscapes dominated by variable habitats. Or otherwise, factors that vary at a geographical scale: i.e. temperature clines and the extent of productivity along latitudinal gradients.

The third and final criticism made, is that the theory is "species neutral: i.e. it assumes that all species are independent and equivalent" (2000, p. 3). But, as is often the case within complex systems, the dynamics and structure of isolated communities is affected by interactions between species and other components of the system. Because ETIB views all specie as equal, it overlooks the potential impacts of inter-specific interactions. This species neutral model fails to address patterns in species composition when, "the most interesting patterns in biogeography concern not just how many, but which species inhabit islands". This is paramount when consideration is given to the challenges of conserving biological diversity on island or within isolated fragments of ecosystems. There is no justification in viewing rare, geographically restricted species as the same as common, wide-ranging ones.

When in reality, it is quite the opposite: endangered species are unique, and they are fighting to survive "because of their relatively high resource requirements, limited dispersal abilities and high sensitivity to human disturbance" (2000, p. 4).

This point is particularly pertinent to the present study, as the focus species all display 'generalist' habits and have become widespread throughout the study area. If their presence continues to increase into the future, to the same extent it has in the past, so does the likelihood their populations will have a detrimental impact upon 'specialist' species, some endemic to the region, that are fighting to maintain limited distributions within the study area.

Despite these criticisms, ETIB has remained a major biogeographic paradigm, as it provides a foundation upon which a framework for the future can be built. Ideally, says Lomolino, it should remain simple, "based on the conceptual tripartite of biogeographic processes: immigration, extinction and evolution" (2000, p. 4). It needs be hierarchical, to factor in system features i.e. isolation, immigration filters, area, geology and climate, that influence these processes at the temporal and spatial scales involved. Foremost, it must include interplay amongst system components i.e. inter-specific interactions, as in the end, "many biogeographic patterns derive from, not despite, differences amongst species".

Whilst the scale of the present study does not qualify it as a truly biogeographical account, the physical geography of the study area places it within ETIB paradigms, as it is all but an island, "with sea to the south and west, desert to the north and east" (Seddon, 1972). The study area aligns (approximately) with the 'Southwest Australian Floristic Region' which occupies "a temperate margin of the world's most arid and insular populated continent" (Hopper & Gioia, 2004, p. 623).

Prior to European settlement regional flora and fauna had been in equilibrium, faunal immigration rates were low due to the region's isolation and the geographic barriers that surrounded it. Extinctions were limited as a result of long-term ecological stability within fully functioning ecosystems. The flora and fauna of the region, as well as fire, were used sustainably by indigenous inhabitants.

With the arrival of Europeans, changes were wrought on the landscape; trade and transport extended to and from far shores. A multitude of exotic floristic and faunal species were permitted entry, or arrived by accident, only to pervade once pristine ecosystems. The equilibrium of the region's natural systems was undone, and to this day has not balanced out. In the case of birds, a number of generalist species have become abundant and widespread, benefiting from human habitation. On the other hand, specialist species are in decline unable to survive the impact of human settlement. Habitat loss and degradation, as well as competition from exotic, and potential invasive species, blight their continued existence.

2.1.5 Ornithological Literature:

At the commencement of this research, several field guides were consulted to précis the physical description, feeding and breeding habits and historic range of the focus species. Nomenclature for the research was based on *Field Guide to the Birds of Australia* (Pizzey & Knight, 1997) (as per Christidis and Boles 1994). All volumes of *Birds of Western Australia* (Serventy & Whittell, 1948, 1951, 1962, 1967, 1976) were also consulted (as each edition provided a detailed avian history of the region specific to the era it was published). A paper by Dom Serventy (1937), *The Menace of Acclimatization*, was also reviewed.

In compiling the case-study profiles, a number of texts were consulted including: *Common Australian Birds* (Bell & Bell, 1969), *Field Guide to the Birds of Western Australia* (Storr & Johnstone, 1979); A field guide to Australian birds' nests and eggs (Beruldsen, 1980); *The Food of Australian Birds – Non Passerines* (Barker & Vestjens, 1989); *The Illustrated Dictionary of Australian Birds by Common Name* (MacDonald, 1987); *Handbook of Western Australian Birds* (Johnstone, 1998), and finally, *The Complete Book of Australian Birds* (Schodde & Tidemann, 1997, 2003).

Background information as to the changes in avian populations and distributions within the study area was found in *Birds of Southwestern Australia: an Atlas of Changes in Distribution and Abundance* (Saunders & Ingram, 1995). Also reviewed were *Introduced Birds of the World* (Long, 1981) and *Introduced birds and mammals in Western Australia* (Long, 1988), both which gave detailed summaries of avian invasion events and addressed the possible impacts on local ecosystems, as well as provided background on global species invasion events. Consecutive issues of "The State of Australia's Birds" (2003-2010) were also consulted.

Finally, in order to ensure an exhaustive review of ornithological sources related to the target species had been undertaken, relevant volumes of *The Handbook of Australian, New Zealand and Antarctic Birds* (Marchant & Higgins, 1990) were also consulted.

Other than these texts, other sources were also sought to investigate avian pest species within the study area, Australia and throughout the world. In relation to the study area, these included fact sheets and reports issued by the Department of Agriculture and Food, Western Australia, pertaining specifically to the Indian Ringneck Parrot, Sulphur-crested Cockatoo and Rainbow Lorikeet. These species, although not retained as target species, feature in the concluding remarks in relation to strategies developed to manage invasive species (as identified by Emerton & Howard, 2008). These are examined fully in the concluding chapter.

From the DAFWA sources it was ascertained that the Indian Ringneck is a high priority target for the department with reported sightings assigned a 'rapid response team' to recapture specimens. It is reported that between 2005- 2007, at least twenty-five feral Indian Ringnecks were recovered. Some are thought to have survived in the wild for at least four years and two

groups had reportedly bred. Several of the captured birds had leg bands that identified them as having arrived to the area via bird breeders (DAFWA, 2007).

The Sulphur-crested Cockatoo, whilst not presenting a threat of the same magnitude, is already at large in parts of the Southwest. The species was either introduced to, or escaped into the region prior to 1935. It is now present in an area that extends from Waroona north to Bullsbrook and Muchea. It has also been recorded in the Darling Range between Darlington and Kalamunda. Its range may extend as far south as Harvey and it has bred at both Pinjarra and Guildford. The current Southwest population is estimated at 200-300 birds (DAFWA, 2001).

The species is the target of objectives designed to contain feral populations, with their numbers 'reduced whenever possible' to limit populations and prevent damage to crops (it is a recognised grain crop pest in other States). In the study area it would compete for food with the species such as Western Long-billed Corella (*Cacatua pastinator*) and Western Short-billed Corella (*Cacatua sanguinea*). Competition for nest holes would also likely occur with Baudin's Cockatoo, Carnaby's Cockatoo and the forest Red-tailed Black Cockatoo, which are already threatened from habitat loss and degradation (due to reduced feeding and breeding habitat).

Whereas, in the case of the Rainbow Lorikeet, the only remaining option is to manage it with a view to limiting population growth and its spread into new areas. Pre-emptive strategies of eradication or containment were either not implemented, or initiated too late. When first recorded in Perth in the 1960s, no action was taken to remove the wild birds. From fewer than ten escaped or released birds, the population now extends over a large part of the metropolitan area and was expected to exceed 20,000 birds by 2010 (Chapman and Massam, 2007).

Research of the Rainbow Lorikeet undertaken within the study area has identified it as a pest threat to cherries, apples, pears and stone fruit. In the Swan Valley, it targets commercial wine and table grape crops (it is a serious pest threat to grapes in other parts of Australia).
In the Perth Hills it also damages orchard fruit crops. The species is also exerting competition pressure on native species for nest sites and food. This may result in a negative impact on hollow-nesting species such as Purple-crowned Lorikeet (*Glossopsitta porphyrocephala*), Elegant Parrot (*Neophema elegans*), Red-capped Parrot (*Purpureicephalus spurius*), and Western Rosella. It also poses a potential disease risk to wild and captive parrots because they are carriers of psittacine beak and feather disease.

Other than these economic and ecological impacts, the birds also diminish community aesthetics, as they foul outdoor areas and vehicles with their droppings. They are also noisy when they approach in flocks between 10-50 birds. A large population that has established near Perth Airport also poses an aircraft-strike risk. A pest risk assessment by DAFWA predicted that the feral population in Perth presented an extreme risk to the social, environmental and agricultural values of the state (Chapman, 2005).

Other than examination of these aviculture species, invasion phenomena relating to 'global species', specifically, Common Starling (*Sturnus vulgaris*), Tree Sparrow (*Passer montanus*) and House Sparrow (*P. domesticus*) were also investigated. These species are the focus of sustained vigilance by authorities to keep them out of the state (and eradicating them should they arrive), to prevent them from establishing a sustainable population here.

Starlings and sparrows are recognised as being amongst the most invasive bird pests in the world. Both have been used to demonstrate biological invasion phenomena in numerous studies (Including Elton, 1958; Hengeveld, 1989; Long, 1981). The Common Starling, which was once limited to parts of Europe, has colonised North America. It has spread so widely that it is now considered an environmental and economic pest. It has had a detrimental effect on native bird species, and causes extensive crop damage and soiling of stock-feed.

In Australia, the Common Starling it is abundant throughout South Australia, Victoria, New South Wales, Southern Queensland, and Tasmania and parts of the Northern Territory where it is classified as an environmental and economic pest. It damages fruit and grain crops, as well as spoils stock-feed, with the cattle, pig and poultry industries adversely affected. It has also been linked to reduced breeding success in native parrot species. When present in large flocks, accumulated excrement poses a disease risk as it harbours pathogens harmful to humans.

It was first recorded in Western Australia in 1936, when a single observed bird was removed at Gingin. Since 1971, individuals and small flocks have crossed the Nullarbor Plain to enter the state. Whilst these have been targeted by DAFWA, and most have been removed, small isolated populations have become established in the south-east, near the towns of Munglinup and Condingup.

The species remains the target of continual controls by DAFWA, with two main aims: (i) to prevent increases in Starling numbers and settlement of other areas, and (ii) to eradicate the species from the State (a few birds have also been recorded in the far north). Under legislation administered by DAFWA, the Common Starling is a declared pest. None are allowed for import and none are to be kept anywhere in the state (Kirkpatrick & Woolnough, 2007).

Similar vigilance is extended to the management of the Tree Sparrow and House Sparrow, which are also declared pests. House sparrows are often captured in Starling traps along the south coast of South Australia, which suggest it is trying to extend its range.

Like the Starling, sparrows damage fruit and cereal and fruit crops and spoil animal feed and stored grain with their droppings. Their nests block gutters and downpipes which often results in damage to buildings. They are also pests in areas where food is eaten. Birds that arrive here on ships potentially harbour exotic diseases harmful to humans and animals. They also increase ecological competition with native birds for food and nesting sites.

The Tree sparrow, native to southern China and parts of south-east Asia, has introduced populations in other parts of south-east Asia and North America. In Australia, it is present in Melbourne and northern and central Victoria. It is also present in the Riverina region of New South Wales. The House Sparrow, native to Eurasia and North Africa, has been introduced into the Americas, South Africa, New Zealand and several islands. In Australia it is found in most of the eastern half of the mainland, Tasmania and the Northern Territory (DAFWA, 2005).

The absence of, or limited numbers of these birds that make it into Western Australia are testament to the success of the strategies being applied in the control of these species.

2.1.6 Geographic Information Systems:

To better understand the workings of Geographical Information Systems (GIS) software and functions, and assess the suitability of GIS to the research project, a number of texts were consulted: *The GIS Book* (Korte, 1992); *Analytic Mapping and Geographic Databases* (Garson & Biggs, 1992); *Geographic Information Systems in Ecology* (Johnstone, 1998); and *Fundamentals of Geographic Information Systems* (DeMers, 2000). These texts provided insights into how the technology worked, and how to prepare the data for processing and analysis as well as summarised formats the analyses could take. Also consulted was *Spatial Statistics in ArcGIS* (Scott & Janikas, 2010), for further clarification of the types of spatial statistics that could be drawn from the analyses.

2.1.7 Nomenclature:

Finally, nomenclature for avian species not included in Christidis and Boles (1994, 2008), was taken from either *Distribution and Taxonomy of Birds of the World* (Sibley & Monroe, 1990), or the Association of European Records and Rarities Committees (2003).

Plant species names (as well as descriptions and distributions) were based on *Western Weeds: A Guide to the Weeds of Western Australia* (Hussey, Keighery, Cousens, Dodd, & Lloyd, 1997); and *Leaf and Branch* (Powell, 1990).

3 METHODOLOGY

3.1 Overview:

Central to the research design is the use of Geographic Information Systems (GIS) software to perform spatial and temporal analyses of historical sightings data. Following consultation with specialists in GIS from Edith Cowan University and Department of Environment and Conservation Western Australia [DEC], ESRI *ArcView 9.2* (2007) was selected based on recommendations of its capabilities and user-friendly inter-face.

The choice of GIS as a core methodological tool had a significant impact on the choice of the focus species. Primary selection criteria were (a) availability of data; (b) volume of data; (c) accuracy of data and; (d) cost of data acquisition. Some species initially considered for inclusion met these criteria but were excluded for other reasons (refer Chapter 1, page 2).

The final species chosen for the study were: Australian White Ibis (*Threskiornis molucca*), Spotted Dove (*Streptopelia chinensis*), Laughing Dove (*S. senegalensis*); and Laughing Kookaburra (*Dacelo novaeguineae*).

3.2 Acquisition of Data:

Data acquisition commenced with a written request to the following sources (Appendix 1). All acquisition requests were granted:

- Dr SJJF Davies, Former Director, Royal Australian Ornithologists Union (Raoul);
- Birds Australia (BA) (formerly RAOU);
- Birds Australia Western Australia (BAWA);
- Australian Bird and Bat Banding Scheme (Australian Bird and Bat Banding Scheme);
- Curator Ornithology, Ron Johnstone, Western Australian Museum (Storr-Johnstone Data Bank) (SJDB);

Application was also made to DAFWA. However, as data was not available for all species it was not sought for inclusion in the database.

3.3 Compilation of database:

The greatest methodological challenge lay in constructing an integrated, standardised database from datasets compiled of records gathered using different collection methodologies and data storage systems. Primary data included hand-written records listing a location name only; other digitised records were stored in a purpose-built programme not configured to export data. Some records recorded site locations in ‘Degrees’ and ‘Minutes’ (hereafter termed ‘Geographic Coordinates’).

A requirement of *ArcView 9.2* was that all datum had to be shows as a Decimal Degree coordinate (to a minimum of three decimal places for accuracy), making data conversions necessary.

A further complication was that each record entered had to be of equal value, as the raw data included records pertaining to multiple individuals (2+). Furthermore, the records included breeding data that required identification in a way that *9.2* would recognise and not confuse with other identifiers.

Whilst the conversion processes are detailed later in the chapter, the latter challenges were addressed in the following manner:

- Each record regardless of the number of individuals it related to was awarded a single value;
- Records of breeding birds were identified in a dedicated column marked '1'for breeding and '0' for non-breeding records.

The final methodological challenge relates to differences in geodetic datum between maps imported into *ArcView 9.2* and those generated by the programme (pairing of maps demands a common geodetic datum). The *ArcView 9.2* programme is configured to 'modern' geodetic datum, Geocentric Datum of Australia 1994 (GDA94), whereas some imported maps were configured using earlier systems, Australian Geodetic Datum 1966 (AGD66) or 1984 (AGD84).

Such 'datum shifts' are common and conversion capabilities are a feature of *ArcView 9.2.* Summarily, GDA94 datum uses Earth centred measurements, whereas AGD66 and AGD84 use measurements offset from the Earth's centre of mass (by about 200m): This translates to a difference of approximately 200m in distances between the earlier datum types, and modern datum type. As such, the difference was seen to fall well within the accepted 5% margin of error given the total km^2 of the study area. For a detailed synopsis of Australian datum types, refer to the *Geocentric Datum of Australia Technical Manual* (Intergovernmental Committee on Surveying and Mapping, 2006).

File construction and analyses were executed using Microsoft (MS) Windows operating systems, specifically MS Office 2003 applications (other than *ArcView 9.2*). Initially, records from each source were assembled into species-specific MS Excel spreadsheet files in a standardised format that included a formula to convert records from Geographic Coordinates to Decimal Degrees coordinates.

Initially, those records listed as a location name only had their corresponding Decimal Degree coordinate inserted manually using codes listed in *Australian Gazateer* (2004) (Australian place name register with corresponding geographic datum ascribed by State, Commonwealth and Territory authorities).

The process was laborious and an alternative method was sought. The six MS Excel (.xls) species files were then merged to create a Master file containing all records. A search for alpha/numeric errors was executed. Locations missing a coordinate were left blank.

This file was then exported into MS Access for conversion to a database (.mdb) file extension suited to file sharing with *ArcView 9.2*. Here an alternative was found to insert Decimal Coordinates for locations lacking one. A function of the programme allowed the creation of a 'query' to marry the coordinate listed for the location in *Gazateer* (2004) to the place name in the file. Another alpha/numeric search was executed to correct any remaining errors or anomalies.

There were two final preparatory steps undertaken in the MS Access file format: the addition of a 'year only' (yyyy) column to standardise, simplify and unify date records; and the addition of an 'Era' column to divide data into sets to allow for comparative analyses, comprising all records from 1898 – 2007. The years of introduction spanning from 1898-1952, were defined as 'Era A'. This period was extended to include 1953 to boost records for the Australian White Ibis which was first recorded in the study area in 1952. Doing so also allowed the remaining years to be divided into two equal periods, resulting in the following demarcation: Era A, 1898 – 1953; Era B, 1954 – 1980; and Era C, 1981 – 2007. The datasets included in each phase, from each source varied (Table 3.1).

Table 3.1: Chronological Eras: dates, duration and data included in each

Era	Records
A: 1898 – 1953 (55 years):	RAOU, SJDB;
B: 1954 – 1980 (26 years):	BA, BAWA, ABBBS, SJDB;
C: 1981 – 2007 (26 years):	BA, BAWA, ABBBS, SJDB.

3.4 Data Sources:

As mentioned previously, the purpose built database for the *ArcView 9.2* analysis is comprised of records extracted from a number of different sources. A summary of contributors is included below, including a brief history of the organisation, data collection methods and storage. Coordinate conversion processes are also detailed.

3.4.1 Royal Australian Ornithologists Union (Raoul):

The 'Australasian Ornithologist's Union', first convened in 1901 with the aims of advancing and popularising ornithology and protecting useful and ornamental avifauna. It incorporated birding groups from mainland Australia, Tasmania and New Zealand (the latter formed its own society in 1939). It published a magazine, *The Emu*. In 1910, King George V, bestowed the title 'Royal' to the group, the apostrophe was lost and it became the 'Royal Australasian Ornithologists Union' (Robin, 2001).

Historical RAOU data was made available courtesy of a former Director and Honorary President; and principal architect of the inaugural *The Atlas of Australian Birds* project. The data, which provided the earliest records, was stored on microfiche. Relevant records were first handwritten and then entered into a spreadsheet. The data listed a taxonomic code number for each species alongside a corresponding geographic coordinate of the location of the sighting (this same taxonomic code was retained for each *Atlas* project). Breeding records were identified with an asterisk (*) and annotated.

The RAOU records included in the database are dated from 1897-1976. The geographic coordinates of sightings were recorded as 'Degrees' and 'Minutes'. As stated previously, *ArcView 9.2* required coordinates as Decimal Degrees. Records requiring conversion had the following formula applied:

Degrees	+	(minutes/60)	+	(seconds/3600)	E.G.:
21 degrees	+	08minutes	+	10seconds	=
21 degrees	+	(8/60)	+	(10/3600)	=
21 degrees	+	0.13333	+	0.00277	= 21.1361

As there were no 'seconds' values ascribed to the RAOU records, the conversion formula entered into the MS Excel spreadsheet was simplified to read as follows:

= cell reference Degree Latitude + cell reference Minute Latitude/60, or;
= cell reference Degree Longitude + cell reference Minute Longitude/60

Some of the inaugural *Atlas* (1984) data was also listed and transcribed but this was later set aside for digital records provided by Birds Australia.

3.4.2 Birds Australia (BA):

In 1997, the RAOU sanctioned a change of trading name to 'Birds Australia' (BA), although 'RAOU' remained the registered name of the group (Robin, 2001). In July 2011, BA merged with Bird Observation and Conservation Australia (BOCA) and became affiliated with the international 'BirdLife' organisation to better utilise combined resources. As at January 2012, 'BirdLife Australia' came into being. The group has a financial membership exceeding 10,000, a further 25,000 supporters, 28 branches, two reserves, two observatories, a members' magazine, *Australian BirdLife* and two peer reviewed scientific journals, *Emu* and *Australian Field Ornithology*. Data from this source includes records compiled for all atlas projects as per below:

- *The Atlas of Australian Birds* (Blakers *et al.*, 1984); (Records dated 1977-1981);
- *The New Atlas of Australian Birds* (Barrett, Silcocks, Barry, Cunningham, & Poulter, 2003) (Records dated 1996-2000);
- Online *Birdata* (https://www.birdata.com.au); (Records dated 2001-2007).

As stated previously, primary first *Atlas* records transcribed from microfiche were substituted with digital data provided by Birds Australia to speed processing. The atlas series, commencing with Blakers, Davies and Reilly (1984) comprises sighting records for all Australian avifauna (including introduced species), from all States and Territories, "including islands and waters separating them from the mainland, and seas up to 50km offshore... and from large embayments" (1984, p. xvi).

The outer limits of data collection were set at 8°S and 44°S and 112°E and 154°E. Areas outside this zone were considered too remote and difficult to access and as possessing avifauna too different from the rest of the continent. The project, funded by Commonwealth Government grants, was the first large scale computer based faunal distribution project conducted in Australia. Species taxonomy was based upon the *Checklist of the Birds of Australia, Part 1, Non-Passerines* (Condon, 1975) and *Interim List of Australian Songbirds, Passerines* (Schodde, 1975).

Data collection kits recorded data at species level and asked for a sightings date and location coordinate (each species was ascribed a coded number). Data collection was for a five-year period, commencing 1 January 1977 to November 1981. Data collection was undertaken within southern hemisphere seasons, with variations between the tropical north and temperate south, recognised as a limitation.

The scale applied to the project was Transverse Mercator Grid (10km) units based on lines of latitude and longitude. This universal system had been successful in other projects, and maps were readily available. Fixed grid lines of 1° and 10' apart were adopted. The target for data collection was set at a minimum of one visit to all (812) 1° blocks. Participants were asked to record in 10' blocks where possible. Records were based on 'presence' and 'breeding' only within each grid block. For breeding records to count, the observer had to sight eggs, chicks, or dependent, downy young. Empty nests were excluded along with courtship displays i.e. pairs feeding, fighting, copulating or nest building. The presence of a nest can be environmentally driven and breeding may not occur which makes them unreliable indictors of breeding range.

Following submission, records were entered into computer software programme pioneered by the Commonwealth Scientific and Industrial Research Organisation [CSIRO]. They were then sorted into 1° blocks, of latitude and longitude and coded for locality and specimen type (which was verified at 99.75% accuracy). The programme, *CSIRONET*, identified inconsistencies (incorrect dates, coordinates, duplicate or missing records).

All records "were assumed to be accurate until queried (Blakers *et al.*, 1984, p. xxiii). Officially, 2969 people contributed records, although unofficially, the number probably exceeds 3000. In Western Australia, 13,349 record sheets were submitted. They contained 282, 313 records relating to 467 species (of which 325 were breeding), thus providing a comprehensive snapshot of the State's avifauna.

The methodology adopted for the *New Atlas of Australian Birds*, (Barrett *et al.*, 2003) although based on its predecessor, was improved by the use of technology such as Global Positioning Systems receivers and survey sheets that could be digitally scanned and entered. Fieldwork commenced in August 1998 and continued until late in 2002. Within this period more than 7,000 participants completed 279,000 surveys, producing 4.7 million records of 772 bird species. (Barrett *et al.*, 2003, p. 15). Coverage extended to territorial waters, as well as Christmas, Cocos and Norfolk Islands.

There are however limitations in both atlases: Data collection was limited to specific time-periods reflecting weather and environmental conditions only for that time; maps may have been incomplete due to poor observer behaviour; breeding records were not thorough (especially in regions where site access was limited). Observer behaviour also influenced the maps: i.e. variability in the number and duration of site visits made. Despite these limitations, both projects were constructed using proven data collection methods and analysis was subject to rigorous processes to attest to accuracy in the outcomes.

The limitations inherent in both the hard-copy atlases have been significantly overcome since the project moved into an 'ongoing phase', whereby survey data is updated online via the *Birdata* website (http://www.birdata.com.au). To the period ending 2007, in excess of 7000 participants contributed 459,000 surveys containing 7.5 million bird records (Silcocks, 2011). Data reported in the annual publication of The State of Australia's Birds is sourced from the *Birdata* online atlas.

Although few surveys were carried out between the first and second atlas, surveying for *Birdata* has remained constant to keep it current. For the present study, records retrieved from *Birdata* were for the period 1998-2007. Unlike previous atlas projects that collected data in grids and sometimes relied on single-site visits, the method for *Birdata* surveys is to conduct 2 hectare/20 minute; or fixed route/ monthly survey and record precise site coordinates. This method improves data accuracy and allows for repeat surveys at the exact location. The *Birdata* database also includes the complete datasets from previous atlases (Birdlife International, 2011a). It is recognised internationally as one of the most comprehensive faunal databases compiled.

Prior to release of the data, Birds Australia required an 'Application for Data' form to be completed (Appendix 2). Once approved, the data was sent as digital copy in CD Rom format (with files constructed in MS Excel). The records included listings for the 'First Atlas'; 'New Atlas' and 'Nest Record Scheme' (NRS). The dataset for the New Atlas included *Birdata* records from 2002-2007 inclusive. The primary files for each dataset were not species-specific. Records were first sorted, grouped then saved into individual species MS Excel spreadsheet files.

These files were then edited further to fit the spreadsheet format tailored to standardise the data in readiness for *ArcView 9.2.* Several fields from the primary data were removed. From the First Atlas, 'Link', 'Sheet', 'Species No.', 'Geographic Coordinate', 'Second Date', 'Block', 'Source' and 'Reliability'. From the New Atlas, non-decimal Geographic Coordinates were removed. For Nest Record Scheme data, 'Sheet', 'Species No.', 'State', 'Block', 'Height Eggs', 'Height Plants', 'Edge', 'No. of Visits', 'Time Zone', 'Success/Failure', 'No. Out' and 'Location' were removed.

3.4.3 Birds Australia Western Australia (BAWA):

Sightings records retrieved from BAWA were stored in an 'in-house' digital database located at group headquarters, Peregrine House, Floreat. The database, which pre-dates the New Atlas, uses a system whereby members complete cards listing sightings at a particular location: whether for a few hours, a day, a few days or a month. It was first developed for use in national parks, then later utilised for BAWA excursions, and finally extended to include visits to Shires and landmarks. Information pertaining to the database was provided by Suzanne Mather (Editor, *W.A. Birdnotes*) (Personal Communication, Suzanne Mather, 15 June 2011).

As stated previously, the records included in the database were not collected within specified data collection periods or using a formal methodology. Contributors submit a record card. The card records the contributors name and contact details, date, location name, latitude and longitude. It also includes a checklist (species identification number/name) upon which species sighted are marked off. Records can be taken during walks or visits to parks, when on tour or holidaying. As a rule, the latitude and longitude figures recorded are the gazetted coordinates for the locality and are not site specific.

The database, into which these records are entered, was designed specifically for BAWA. It is usually accessed 'in-house' only which resulted in the records not be suitable for export as whole datasets to an external source due to software incompatibility.

To overcome this, records for each of the focus species where called up, 'cut' from the database and 'pasted' into MS Notepad, a programme common to BAWA, campus and my home computers. Records for each species were stored externally on disc. Search parameters 01/01/YY to 31/12/YY, commencing with the earliest year data was entered for that species and ending 31 December 2006 were applied. Parameters for 2007 were amended to the date of the latest data update (01 November 2007) prior to the date of retrieval (07 November 2007).

The raw data from MS Notepad was first tabled in MS Word whereby the Geographic Coordinates pertaining to the locality were removed retaining only the locality name. This amended table data was then pasted into species-specific MS Excel spreadsheets. The completed files were later exported into MS Access for final processing, including the addition of decimal coordinates (listed in *Gazateer* 2004), to localities listed by name only).

3.4.4 Australian Bird and Bat Banding Scheme (Australian Bird and Bat Banding Scheme):

Despite earlier attempts at bird banding by the RAOU and Bird Observers Club, the 'Australian Bird and Bat Banding Scheme' did not formally commence until 1953 under the CSIRO Division of Wildlife Research Division (bats in 1960). From 1984 it was coordinated nationally by the Australian National Parks and Wildlife Service (ANPWS), until designated to the Department of Sustainability, Environment, Water, Population and Communities. The database now exceeds 2 million records.

The current data management system was introduced in 1984 when the scheme was taken over by ANPWS to improve access and the availability of data. Data is managed by project and species and is submitted digitally in a range of formats. Data retrieval is based upon search parameters e.g. species, latitude, longitude and breeding (Australian Bird and Bat Banding Scheme, 1992).

Upon receipt of my letter request for data, ABBBS emailed a summary of available data, comprised of records submitted by forty-three registered banders. Of these, thirty-five had pre-approved use of the data but approval was required from the remaining banders. Of these, four approved the use of their data via email, whilst my attempts at contacting the others failed. These, along with a directive that I had not succeeded in gaining approval from the others, were forwarded to ABBBS. Once permission for use of the data was validated, an 'Agreement for the Supply of Data' (Appendix 3) was sent by return email. The Agreement was completed, signed and forwarded as hardcopy to ABBBS Head Office, Canberra. Subsequent to that, records were emailed as an attachment in MS Excel format (received 4 March 2008).

All banders, regardless of their classification record information on a 'Field Data Sheet'. The sheet records information about the bander and the species banded, including: banders name, authority code, project number; time zone; band or retrap number; species name and code; species age; how aged code; species sex; how sexed code; release date; release time; locode; encounter method code; status code; weight; head-bill measurement; wing length; tail length, and feather moult count. A sample has been appended, along with raw and processed data.

3.4.5 Storr-Johnstone Data Bank (SJDB):

This extensive data bank lists records first assembled by Dr. Glenn Milton Storr BSc. MSc., PhD. (Zoology), a graduate of University of Western Australia who commenced his studies in Zoology in 1953 after assisting prominent ornithologist, Dr D. L. (Dom) Serventy, in 1952, at the Eyre Peninsula. He was later appointed to the position of Curator of Ornithology and Herpetology, at the Western Australian Museum, 1965-1986.

As a long-time member of the RAOU, he served the organisation throughout his career. He commenced compilation of the SJDB in 1967 " (Personal Communication, Ron Johnstone, 30 June 2011).

Responsibility for the maintenance and management of the data bank then fell to his successor, Ron Johnstone, the current Curator of Ornithology since 2001. Like his predecessor, he is also a long-time member (40+ years) of BA (now BirdLife). His contributions to the SJDB began in 1970 and he continues to the present day. As with Dr. Storr, the SJDB has been largely a personal endeavour.

The project was developed out of a need for a more expansive databank than that derived from species distribution maps based on specimens alone. As one of the principal architects, Mr Johnstone describes the SJDB as "one of the largest and most detailed bird data bases in Australia" (Personal Communication, Ron Johnstone, 30 June 2011), taking in WA, Northern Territory, Queensland, Christmas and Cocos-Keeling Islands, as well as Eastern Indonesia. The data it contains can be applied to studies "on distribution, status, habitat preferences, migration, food, breeding, interpreting historical changes in the avifauna and for studies of ecology and conservation." (Personal Communication, Ron Johnstone, 30 June 2011).

It also includes unpublished notes and diaries of hundreds of fieldworkers, naturalists and collectors, as well as extracts from the literature and details of the specimens held in Australian and overseas museums and private zoological collections. The SJDB forms the basis for numerous regional avifauna monographs as well *Handbook of Western Australian Birds* (Johnstone, 1998, 2004).

It has had several significant contributors including J. Long and S.J.J.F. Davies and D.L. Serventy. Nomenclature and sequence follows that of Johnstone (2001) with adaptation to Christidis and Boles (1994, 2008).

Access to this privately held resource is granted by Mr Johnstone. A data request listing the focus species, study area boundaries and intended use of data is first directed to him. Upon his approval, databank records are appraised and the cost of record retrieval estimated. Fortunately, in support of this academic endeavour, data was provided at a nominal fee to allow budgetary constraints to be met.

Photocopied sheets (A3 size) of the SJDB records were provided. All records are hand-written in an assortment of recording styles. Each handwritten record was first entered into individual species files in MS Excel listing a sightings date (dd/mm/yyyy) or year, a location name or specified Geographic Coordinate. As with the RAOU records, sightings represented as 'Degrees' and 'Minutes' required conversion to decimal format for incorporation into *ArcView 9.2*.

The same conversion process was applied to these records as for the RAOU data. The conversions were undertaken in Excel by replicating the formula:

Degrees	+	(minutes/60)	+	(seconds/3600)	E.G.:
21 degrees	+	08minutes	+	10seconds	=
21 degrees	+	(8/60)	+	(10/3600)	=
21 degrees	+	0.13333	+	0.00277	= 21.1361

As there were no 'seconds' values ascribed to the RAOU records, the conversion formula entered into the MS Excel spreadsheet was simplified to read as follows:

= cell reference Degree Latitude + cell reference Minute Latitude/60,

Or;

= cell reference Degree Longitude + cell reference Minute Longitude/60

Again, records listed only as a location were assigned a decimal coordinate after the species-specific MS Excel files were exported into MS Access. Within this programme a 'query' function married location names lacking a coordinate to their corresponding coordinate as listed in *Gazateer* (GEOMET Spatial Metadata, 2004).

This completes the summary of data sources and processes undertaken in preparation of the database compiled for the *ArcView 9.2* GIS analyses. A sample of the completed MS Access database file is included (Appendix 4).

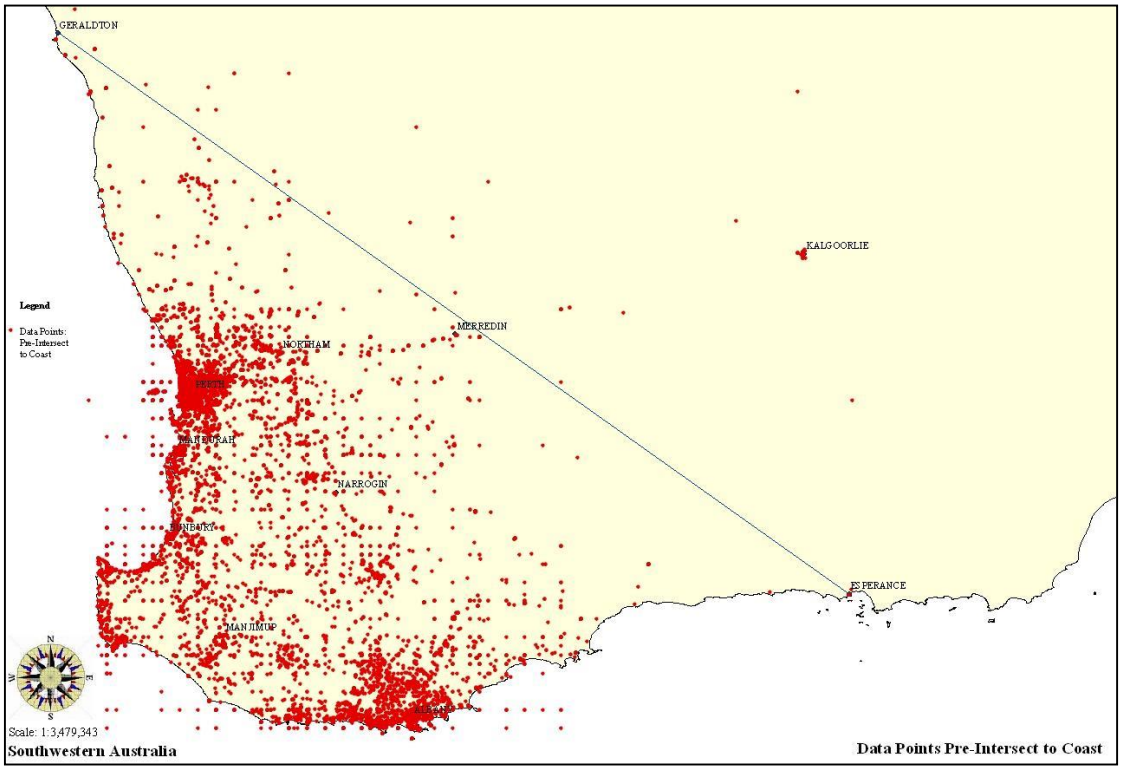
3.5 Geographic Information Systems Processes:

The completed MS Access database (.mdb) Master file was imported into *ArcView9.2* as a series of X/Y coordinates (Decimal Latitude and Longitude). In total 38 070 records (henceforth referred to as data points) were imported. These were displayed on a base map of Western Australia (Map 3.1). From which it was identified that there were errant coordinates. The data points were then intersected to a map of the WA coastline (Map 3.2). The coastline map was taken from Australia's River Basins (2004a), a national spatial database of major hydrologic basins defined by the Geoscience Australia and the Australian Water Resources Management Committee.

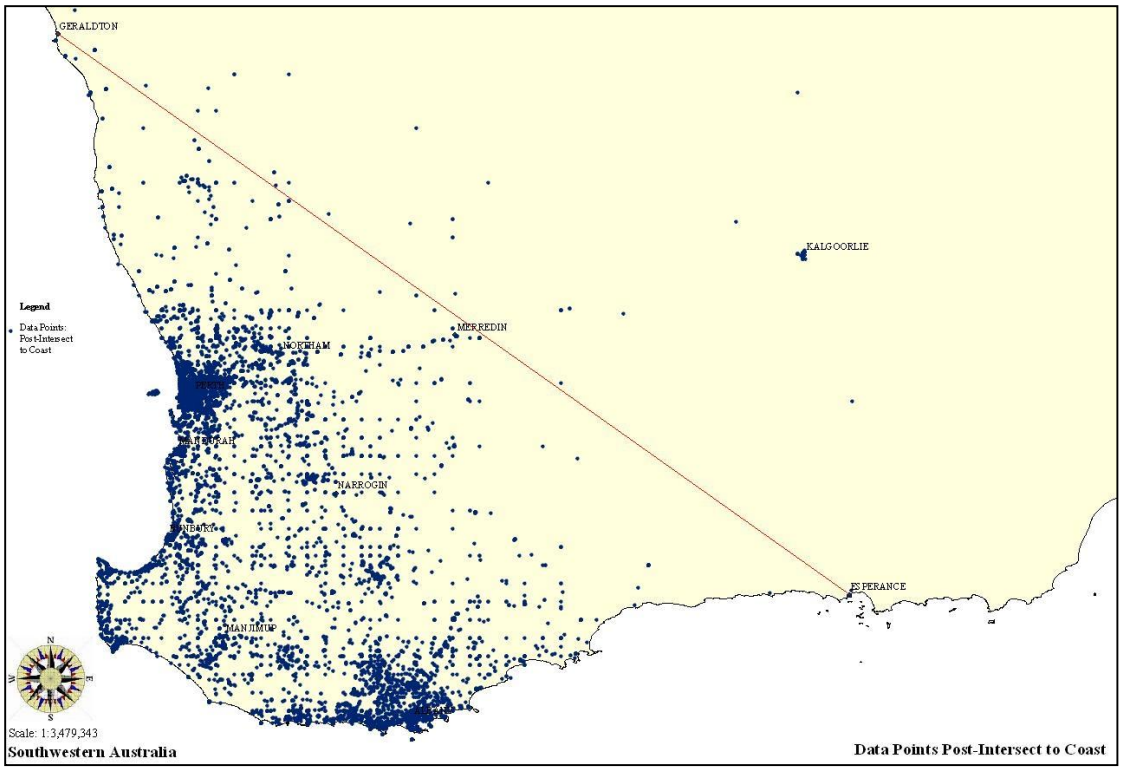
The intersect, calculated to a distance up to 1km from the coastline, resulted in 900 records being stricken from the database. The stricken records fell outside coastal limits well into the ocean. A total of 37 170 records were retained (Table 3.2). Data points that fell outside of the study area boundary but did not intersect to the coast were retained as they represented less than 5% of the total data and therefore did not compromise the accepted 95% confidence level for accuracy.

Table 3.2: Data summary of *ArcView 9.2* database
(Source: The Present Study)

COMMON NAME	ABBBS	BAWA	FIRST ATLAS	NEW ATLAS	NRS	RAOU	SJDB	TOTAL ENTERED	POST-INTERSECT TO 1KM
Australian White Ibis		1376	374	3998		5	281	6034	5931
Laughing Kookaburra	338	2662	2410	7581	78		1514	14583	14191
Laughing Dove	582	1487	1230	4464	136		790	8689	8440
Rainbow Lorikeet		648	24	2976	6		560	4214	4207
Spotted Dove	49	695	387	2588	8	14	309	4050	3933
Sulphur-crested Cockatoo		42	105	93	2		258	500	468
TOTALS	969	6910	4530	21700	230	19	3712	38070	37170
RECORDS OMITTED 900									



Map 3.1:Pre-intersect data points shown on base map



Map 3.2:Post-intersect data points shown on base map

The remaining post-intersect data was filtered using parameters to define all data into eras: Era A (1898-1953); Era B (1954-1980); and Era C (1981-2007). Separating the data in this manner would allow for the production of maps depicting chronological stages of dispersal with each era represented by different colour data points. In addition, the demarcation of data into three 'Era' groups is acquiescent with the *Invasion Process Model* proposed by Lockwood *et al.* (2007) (as discussed in Chapter 2, page 12).

Parameters were also defined to collect 'Initial Sightings' data for each of the focus species. The length of periods varied between species, extending from the earliest sighting record to (approximately) the first decade of sightings. The final temporal snapshot of the data was the creation of "Directional Limits" maps to calculate the distance travelled between the earliest sighting record and the farthest record for each era: to the north, south and east (westerly calculations were not executed as initial sightings records were essentially due west).

Once depicted chronologically, era data was overlaid on maps featuring geographical and anthropogenic attributes of the study area. The maps (imported as 'shapefiles' suited to *ArcView 9.2*) were sourced online, most extensively through Geoscience Australia. Those derived from this source include:

- *Vegetation – Post European Settlement 1988* (2004d) (AGD66);
- *Dams and Water Storages 1990* (2004) (AGD66);
- *Australian Land Tenure 1993* (2004b) (AGD66);
- Australian's River Basins 1997 (2004a) (AGD66);
- *Australian Surface Water Management Areas 2000* (2004) (GDA94);
- *Global Map Australia 1M 2001*(2004c) (GRS 1980 – as per GDA1994);
- *Land Use of Australia, Version 4, 2005-06 (2006)* (GDA94).

Climate data were provided by the Bureau of Meteorology (2007) (GDA1994). The dataset for the climate maps encompassed the period 1889 -2005.

Distribution was not analysed in relation to elevation due to the study area having a regular topography. Other than the undulating Darling Ranges (highest point Mt. Cooke 582m) and the slightly more lofty Stirling Ranges (highest point Bluff Knoll 1095m), the area lacks dividing mountain peaks or valleys. Therefore, map overlays were limited to landuse, climate and hydrology.

The landuse category incorporates areas set aside for conservation, recreation, farming, dryland and irrigated agriculture, plantations, manufacturing and mining. The maps constructed within this category include:

- Conservation and protected areas;
- Managed reserves and protected areas;
- Parks and reserves;

- Recreational and cultural;
- Remnant native vegetation;
- Intensive Animal production and Dairy Farming;
- Grazing and modified pastures;
- Irrigated agriculture;
- Agriculture, horticulture, hay and cereals;
- Irrigated hay, sown modified pastures;
- Irrigated agriculture, flowers, herbs and vegetables;
- Irrigated vine fruit;
- Forrest products and plantations;
- Manufacture and mining; and
- Urban and rural residential areas.

The second category, climate, examines dispersal in relation to temperature and moisture, and includes:

- Average annual maximum temperature;
- Average annual minimum temperature; and
- Average annual rainfall.

The third category, hydrology, is comprised natural and manmade water sources, including:

- Inland water supply;
- Surface and groundwater;
- Waterbodies and waterways;
- Reservoirs and dams; and
- Rivers, river conservation and production areas.

The final land use category featured transport infrastructure. The purpose of overlaying data on road and rail networks was an attempt to reveal if transport vectors acted as a 'bridge' or 'barrier' to dispersal. The overlay of sightings data in relation to aviation facilities was to ascertain if any of the focus species posed a potential threat to air safety due to bird strike: The infrastructure overlaid included:

- Roads (paved and unpaved);
- Railways (metropolitan and regional); and
- Airports (combined site of Perth Domestic and International Terminals and Jandakot Airport).

The data were also spatially analysed to construct a map displaying the '*Spatial Statistics* 'specific to each of the focus species. The depictions are essentially 'spatial snapshots' of the data inputted and the maps produced display:

Standard Distance: A measurement of the extent that features are concentrated or dispersed (Figure 3.1.).

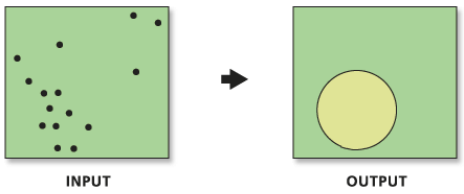


Figure 3.1: Diagram depicting *Spatial Statistics – Standard Distance*
(Spatial Statistics: Standard Distance, ESRI, 2009d)

Directional Distribution: A measurement of whether a distribution of features exhibits a directional trend i.e. are features farther from a specified point in one direction than in another direction (Figure 3.2).

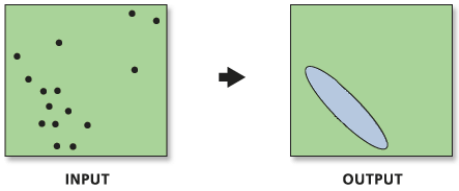


Figure 3.2: Diagram depicting *Spatial Statistics – Directional Distribution*
(Spatial Statistics: Directional Distribution, ESRI, 2009b)

Mean Centre: The depiction of the centre of concentration for a set of features constructed from the average X and Y values of data inputted (Figure 3.3).

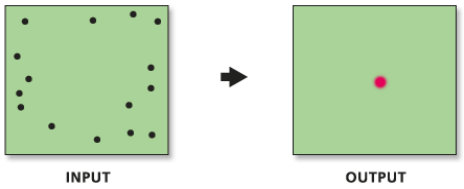


Figure 3.3: Diagram depicting *Spatial Statistics – Mean Centre*
(Spatial Statistics: Mean Centre, ESRI, 2009c)

Central Feature: the most centrally located feature in an input feature class (Figure 3.4),

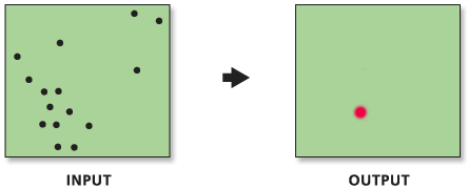


Figure 3.4: Diagram depicting *Spatial Statistics - Central Feature*
(Spatial Statistics: Central Feature, ESRI, 2009a)

The following segment details two types of spatial autocorrelation analyses applied to the data as a means of identifying patterns of 'dispersion' inherent in the data: Moran's I*ndex* function and *Average Nearest Neighbour* function. Dispersion refers to "the internal distribution pattern of individuals within a population" (Emmel, 1973, p. 64). Patterns are primarily influenced by the availability or scarcity of ecological resources within a defined range. However predator avoidance may also be factor, as it is known to influence community dynamics (Brown, Blumstein, 2006; 1999).

As discussed previously, the terms most often used to describe patterns of dispersion are 'Random' 'Uniform' or 'Clumped'. These differ slightly for the present study however, as Moran's I*ndex* function, which measures feature locations and feature values simultaneously, evaluates the patterns expressed as either 'Random', 'Dispersed' or 'Clustered'. The function calculates Moran's Index and *Z-Score* values to evaluate significance: The *Z-Score* signifies if a particular score equals or is above or below the mean score, and if so, how far it deviates from it. A Moran's Index value near +1.0 indicates clustering; whilst an index value near -1.0 indicates dispersion. A high positive *Z-Score* indicates surrounding features have similar values. A low negative *Z-Score* indicates absence of similarity in surrounding features.

Its function is to summarise if a trend is emerging over space and time i.e. is the population remaining concentrated and isolated; or is it spreading. A pictorial depiction of the statistic and associated calculations are shown below (Figure 3.5and Equation 3.1).

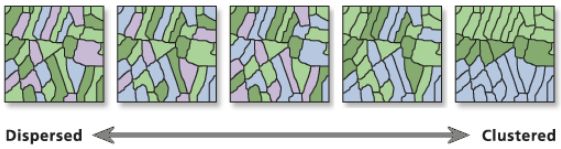


Figure 3.5: Diagram showing Moran's I **spatial autocorrelation**
(Spatial Autocorrelation: Moran's I, ESRI, 2012b)
(Exception to copyright: Section ss 40, 103C for Research or Study)

The Moran's I statistic for spatial autocorrelation is given as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (1)$$

where z_i is the deviation of an attribute for feature i from its mean $(x_i - \bar{X})$, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features, and S_0 is the aggregate of all the spatial weights:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad (2)$$

The z_I-score for the statistic is computed as:

$$z_I = \frac{I - \mathrm{E}[I]}{\sqrt{\mathrm{V}[I]}} \quad (3)$$

where:

$$\mathrm{E}[I] = -1/(n-1) \quad (4)$$
$$\mathrm{V}[I] = \mathrm{E}[I^2] - \mathrm{E}[I]^2 \quad (5)$$

Equation 3.1: Moran's *I* **spatial autocorrelation statistic**
(Spatial Autocorrelation: Moran's I, ESRI, 2012b)
(Exception to copyright: Section ss 40, 103C for Research or Study)

The second tool applied to the data to investigate dispersion was the *Average Nearest Neighbour* function. This calculates an index based on the average distance from each feature to its nearest neighbouring feature. If the calculated distance between each is less than the average for a hypothetical random distribution, the features are 'Clustered'. If it is greater, they are 'Dispersed'. The index is expressed as the ratio of the observed distance divided by the expected distance. The value of the index can only be interpreted if the *Z-Score* is significant.

The *Z-Score* and *Average Nearest Neighbour* Distance' index calculations are based on the assumptions that all features being measured are free to locate anywhere within the study area i.e. there are no barriers; and all are independent of one another. The index and the *Z-Score* are sensitive to changes in the study area parameter so results from this statistic are best when the study area is fixed. These assumptions are met within the present study. It is a useful tool to compare distribution patterns for animal and plant species. A pictorial representation of the statistic and the mathematical equation associated to the statistic are shown below (Figure 3.6 and Equation 3.2

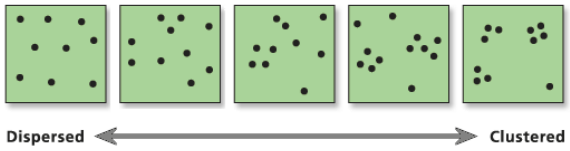


Figure 3.6: Diagram showing *Average Nearest Neighbour* spatial autocorrelation
(Spatial Autocorrelation: Average Nearest Neighbour, ESRI, 2012a)

The Average Nearest Neighbor ratio is given as:

$$ANN = \frac{\bar{D}_O}{\bar{D}_E} \quad (1)$$

where $\bar{D}_O$ is the observed mean distance between each feature and their nearest neighbor:

$$\bar{D}_O = \frac{\sum_{i=1}^{n} d_i}{n} \quad (2)$$

and $\bar{D}_E$ is the expected mean distance for the features given a random pattern:

$$\bar{D}_E = \frac{0.5}{\sqrt{n/A}} \quad (3)$$

In the previous equations, d_i equals the distance between feature i and its nearest feature, n corresponds to the total number of features and A is the total study area.

The z_{ANN}-score for the statistic is calculated as:

$$z_{ANN} = \frac{\bar{D}_O - \bar{D}_E}{SE} \quad (4)$$

where:

$$SE = \frac{0.26136}{\sqrt{n^2/A}} \quad (5)$$

Equation 3.2: *Average nearest Neighbour* spatial autocorrelation statistic
(Spatial Autocorrelation: Average Nearest Neighbour, ESRI, 2012a)

This concludes the functions of GIS utilised for the present study. The final aspect of the methodology relates to the Community Survey and Local Government Area Enquiry.

3.6 Community Survey and Local Government Area Enquiry:

The final aspects of the methodology to be detailed are the 'Community Survey' and enquiry directed to Local Government Authorities (LGAs) regarding Australian White Ibis at refuse sites.

The Community Survey (Appendix 5) included a questionnaire focussed on four aspects relating to the focus species:

- Sightings at respondents dwelling and around their local vicinity;
- Sightings by respondents at other localities within study area limits;
- Utilisation of food and/or water resources at/around dwelling; and
- Utilisation of resources for nesting/breeding purposes at/around dwelling.

The survey contained the common name alongside a coloured (5 x 5cm) photograph along with a description of appearance (mature and immature) and voice to aid participants in identifying the focus species. It was circulated electronically; and as hard copy in the BAWA Newsletter, *WA Birdnotes* (Moon, 2007a) and distributed through local community and sporting groups. Despite these attempts at circulating the survey widely, fewer than 20 were returned, which were too few to support qualitative analysis. However, the responses received were well-detailed and included sightings dates as well as anecdotes about the focus species use of urban habitat to meet ecological needs. Some of the information contained in the responses feature in the individual species case studies.

The enquiry directed to the LGAs (Appendix 6) concerned the presence of Australian White Ibis at refuse sites managed by the Authority. The enquiry was sent as an attachment via email to the Manager of Waste Management Services in each of the LGAs within the study area parameters. The response rate was approximately 90%, enough to garner an overview of the issue.

3.7 General planning:

Fieldwork was also conducted throughout the duration of the study. It was not set up within a formal regime of sites or times; or recorded with a view of being examined statistically. It was simply opportunistic and observational, intended to glean glimpses of the focus species in their colonised habitat. Notes were kept in relation to feeding, nesting and roosting habits and preferences, as well as inter- and intra-specific interactions. At times there were opportunities to photograph them, and where appropriate, these have been included in the research.

Throughout the study the metric system is adopted: hectares, (ha), kilometres (km), metres (m), centimetres (Horvitz), millimetres (mm), kilograms (kg), and grams (g), and henceforth are shown only in abbreviated form.

3.8 Limitations of Research:

Although care was taken to ensure all procedures inherent to the research met rigorous standards, several limitations became evident. The first two have already been addressed within the methodology: the accuracy of sighting data due to the conversion of geographic coordinates from non-decimal to decimal format and conversions between traditional and modern datum types. All non-decimal data required conversion to decimal format, a prerequisite functionality of using GIS. As a result, a distance error of ≤ 200m applies to these records.

The second limitation relates to conflicts in datum types and the compatibility of map layers. Changes in datum have occurred as measurements have become more accurate. As previously stated, some of the layer maps were constructed using 'traditional', earlier geodetic datum types, AGD 66 and AGD 84.

The 'modern' and current Australian datum system is GDA94 and is the default datum built into *ArcView 9.2* for map production. Such datum conflicts, or 'datum shifts' are common and the conversion process is built into the *ArcView 9.2* programme. Essentially, the conversion from the earlier datum types to GDA94 results in a further adjustment of ≤ 200m of the map features. When these adjustments are considered in relation to the total km^2 of the study area, the extents of the adjustments are not significant.

A further limitation arose from showing each record as point data on the GIS maps. Whilst the depiction of a location was effective in displaying spatial dispersal, it did not represent the frequency of each record at each location. This is somewhat limiting in terms of depicting breeding data as it did not allow prolific, successive sites to be differentiated from sites where breeding was intermittent, or relates to very occasional, or even a single events.

The breeding data displayed within each of the case study chapters, whilst based on data compiled for the present study do not represent all of the breeding records listed for each species. Only records which cited the month during which the record was documented were suitable for inclusion.

Similarly, the new sightings localities lists for each era are not comprehensive. They are compiled only from records that list a locality name. This was necessary as the conversion of decimal only locations into place names was problematic as many of the ascribed values did not correspond to place name values listed in the *Gazateer* register. Localities for each era were cross-matched to those of the preceding eras to prevent a locality name being repeated. Preparation of the tables was both complex and time-consuming.

In the data analysis at times sightings are described as being 'in the vicinity of', as when map production was undertaken, whilst *ArcView 9.2* was under licence, the function to allow towns to be labelled was disabled as the names 'crowded' the maps and interfered with the depiction of the data points. This could not be rectified later in order to prescribe more exact locations as the licence conditions did not allow for it.

During the preparation of the GIS maps, every effort was made to adopt systematic labelling of the map content, as well as include accurate legends for the chronological, climate and landuse data. The preparation of the maps however, was undertaken prior to the research terminology being clarified, and as a consequence, some of the maps were incorrectly labelled. The licence conditions of *ArcView 9.2* did not allow for these to be redone and so corrections were made in another digital graphics programme. This has detracted marginally from the presentation of some maps. Similarly, the legend built into the maps during production in GIS, lost clarity when exported into a graphical format and could not be redone. Where appropriate, the legend has been repeated in the text pertaining to those maps affected

The final limitation relates to accessibility to sites and the accuracy of detection and non-detection of the focus species. The issue of detectability is multi-faceted as it relates to the accuracy of observation records taken at a site i.e. a visit at a prescribed time may occur when other species are absent, or are present but not seen or recorded. It can also relate to the likelihood of some species being encountered either more or less, as they inhabit areas with greater or lesser accessibility to pedestrian and vehicular traffic. The problem of non-detection in sampling has been well researched and documented (Hinsley, Bellamy, Newton, & Sparks, 1995; Mackenzie et al., 2002; Nicholas, Boulinier, Hines, Pollock, & Sauer, 1998; Palmgren & Ekholm, 1987). However, it is the latter work of Gu and Swihart (2004) that is referenced for the present study as it presents a clear summary of issues associated with non-detection. The paper reports findings from research into "the impact of non-detection of species occurrence on parameter estimation of logistic regression models" (2004, p. 196).

Their research uses case studies to build logistic regression models and simulations to calculate differences in detection between species. It concludes that it is not unusual for field surveys to fail "to detect species when they are present at a site" (2004, p. 199). However, non-detection occurs mostly amongst rare species with a low detection probability, whereby the "non-detection error can be substantial" (p. 199). Sampling results of common species however, showed that a "…large non-detection error can be non-trivial if sampling effort is limited or sampling method is used that results in low detectability for the species" (p. 199). Therefore, in order to avoid non-detection error in sampling, multiple occasions should be conducted and:

> …should become a standard component of presence-absence sampling protocols, with designs that allow sampling to be completed in a period of time short enough to ensure that local extinction or colonization events do not occur (Gu & Swihart, 2004, p. 202).

In terms of the present study, the focus species are not rare or hard to detect; most sampling was conducted by trained observers, on multiple occasions, using proven survey methods. An assumption is made therefore, that the margin for non-detection errors in the data underpinning the research is negligible.

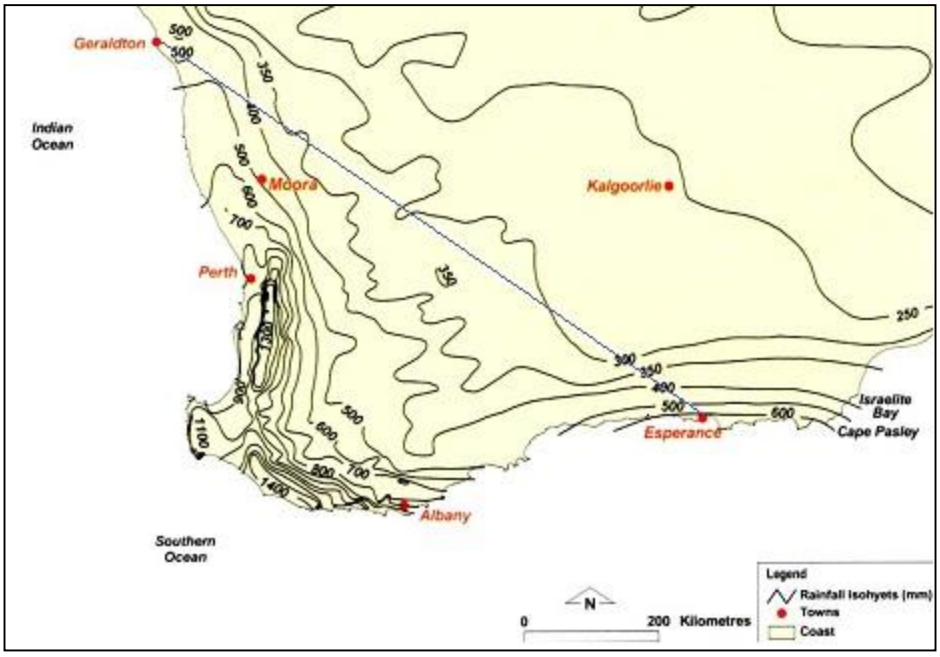
4 THE STUDY AREA

4.1 Delimitation:

The study area, within the state of Western Australia, and from this point forward referred to as the 'Southwest', is delimited by the following boundaries: To the west, by the Indian Ocean; to the north, south and east, by a line that extends south-east from Geraldton (Latitude 28.7790 º; Longitude 114.6145º); passing through Merredin (Lat. 31.4829º; Long. 118.2856º); and terminating at Esperance (Lat. 33.8612º; Long.121.8921º). The eastern boundary (blue line) approximately parallels the 300mm isohyet average annual rainfall zone; a moisture barrier separating the fertile, arable lands that supports the most intensely populated localities, from the arid interior (Map 4.1).

It also takes in three islands off the Perth coast: Rottnest Island (Lat. 32.0052º; Long. 115.5125º); Carnac Island (32.1241º; Long. 115.6644º); and Garden Island (32.2040º; Long. 115.6751º). As well as several small islands (conservation reserves) off the south, south-east coast including Bald Island (Lat. 34.9171º; Long. 118.464º); Breaksea Island (Lat. 35.0629º; Long. 118.0543º); Chatham Island (Lat. 35.0288º; Long. 116.4971º); and Michaelmas Island (Lat. 35.04323º; Long. 118.0376º).

The Houtman Abrolhos (Lat. 28.7175°; long 113.7858), 60km off the Midwest coast do not feature in the study as the distance from the mainland and prevailing winds have acted as a barrier to colonisation by the focus species.



Map 4.1: Delimitation of Study Area boundaries – Southwest Region
(Adapted from Brearley, 2005, p. 15)

4.2 Overview:

The geography of the Southwest region experiences a range of climatic conditions that has "given rise to an interesting and remarkably diverse biota" (Beeston, Hopkins, & Shepherd, 2001, p.28). The cultural heritage of the region is threatened due to historic and contemporary land use practices. It has been recognised globally as a 'biodiversity hotspot' (Mittermeier *et al*., 2004; Myers *et al*., 2000): epitomised by high levels of plant endemism; counteracted by acute habitat loss. (Brooks, De Silva, Foster, Hoffmann, & Knox, 2007): Four localities are listed as hotspots: Mount Lesueur-Eneabba (south of Geraldton); Central and Eastern Avon Wheatbelt; Busselton-Augusta and Fitzgerald River, Ravensthorpe (Department of Sustainability, 2009).

Whilst the region was marginally impacted by the traditional practices of Aborigines, the most extensive alteration of the landscape has occurred since European settlement. Some sites now retain less than 30% native vegetation, such as the Swan Coastal Plain; Blackwood Plateau; Leeuwin-Naturalist and Scott Plains. More intensive clearing occurred throughout the 'Wheatbelt' where more than 90% of native vegetation has been cleared (Beeston et al., 2001). This has had dire consequences for regional biodiversity and despite the cessation of broadscale clearing by the mid-1980s biodiversity remains threatened "through a myriad of other threatening process including salinity...weed invasion, altered fire regimes, feral animals and climate change" (Wheeler, Beecham, Walshe, Penter, & Kietzmann, 2007, p. 267).

The Southwest is the most intensely settled area of the State and has a mainly coastal urban sprawl. Its early economy, driven by mining, agriculture, farming and forestry (Department Environment, 2009) has altered somewhat due to efforts by communities to conserve and protect remnant old- growth forests and promote the establishment of new-growth forests. Eco-tourism (ecologically sustainable tourism) has become viable, based on the region's unique and diverse biota: given that in some areas, more plant species are found "in six square metres… than in six square kilometres in Queensland rainforest or the whole of northern Europe" (Gregson & Larke, 2009, p.1). Other than its botanic richness, the avian biota of the region is also of note, with several 'Important Bird Areas' identified in the region. Each designated such as they support "globally threatened species" (Mather & Gole, 2010, p.3). Discussion now moves toward a summary of the region's physical geography.

4.3 Climate:

The Southwest has a Mediterranean climate with warm to hot, dry summers and mild to cool, wet winters. The Mediterranean climate zone, across the planet, has five associated large subtropical high pressure cells that move towards the poles in the summer and the equator in winter that influence the climate of the Mediterranean Basin (Akin, 1991). It is the 'Indian Ocean High' that impacts the study area climate.

Also referred to as the 'Indian Ocean Dipole' (Australian National Herbarium) this atmospheric high causes the formation of an anti-cyclone which forms systematically through the year, moving west to east over the continent. When present off the coast of WA it manifests as a south-westerly wind that comes off the ocean, cool and damp but rarely bringing rain. As it continues the winds veer south-east, to east, and finally north-east as it passes. The easterly and north-easterly winds move across land and lack moisture. They are extremely hot in summer and very cold in winter. It takes the anti-cyclone five to seven days to traverse the State.

Regular wind changes within generate distinct weather cycles. These usually commence with a south-westerly wind (7-10°Celsius), followed within three or four days (midsummer) by dryland air (30-38°C). The highest temperatures are likely to occur on the fourth day of the cycle with humidity increasing on the fifth and sixth days resulting in a cool change as a new anti-cyclone enters. In summer, a sea breeze rises in the early afternoon. Early settlers named it the 'Fremantle Doctor', due to its rejuvenating effects.

In winter, the anti-cyclones spread out and drift about 1000km north causing moisture-laden air from the ocean, which is often rain-bearing, to spread inland. Characteristically the wettest months are May to October and the driest, November to February. Rainfall variability is between 300-1500mm (Gentilli, 1979), although more recent Bureau of Meteorology (BOM) (2007) data lists rainfall averages from 400 – 1600mm. This should not be construed as an overall increase in rainfall however, with BOM records showing that annual rainfall within the State has gradually declined over the preceding decades (Figure 4.1)

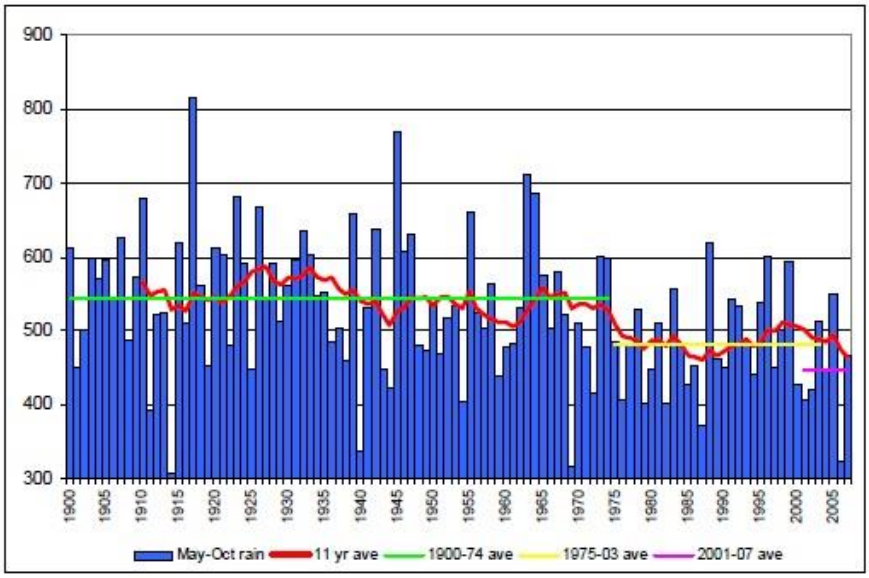


Figure 4.1: Average rainfall, per decade, Western Australia, 1900 – 2005
(Source: Bureau of Meteorology in Department of Water Western Australia, 2009)

The decline in rainfall has been linked to climate change. Modelling by the CSIRO predicts rainfall in the Southwest will continue to decline over ensuing decades. This translates to a reduction in soil moisture and groundwater run-off (Bureau of Meteorology, 2011).

The outlook is serious for the human population and the implications for wildlife are critical, especially for species that are unable, or slow, to adapt to changed environmental conditions. The predicted decrease in rainfall for the Southwest is an anticipated -20% by 2030, and -60% by 2070. Despite criticism of the accuracy of the modeling, it identifies possible future challenges for water supply and wildlife management.

Average annual summer temperatures vary between 20°C -27°C ; and average annual winter temperatures 9°C -15°C (Bureau of Meteorology, 2005). In summer some days peak at over 40°C. Temperature variation throughout the region is considerable, as shown in the table below (Table 4.1), a compilation of maximum and minimum daily temperatures for several locations within the study area (based on Bureau of Meteorology Summary Statistics - All Years on Record to 2011).

Another corresponding model predicts temperature increases within the study area, estimating an increase 1.5°C by 2030, and 5°C by 2070. The prospect of steadily declining rainfall, coupled with temperature increases of these magnitudes, could prove catastrophic for biodiversity in the Southwest region.

Table 4.1: Highest and lowest daily temperatures: Perth and regional centres
(Source: Adapted from Bureau of Meteorology, 2012a)

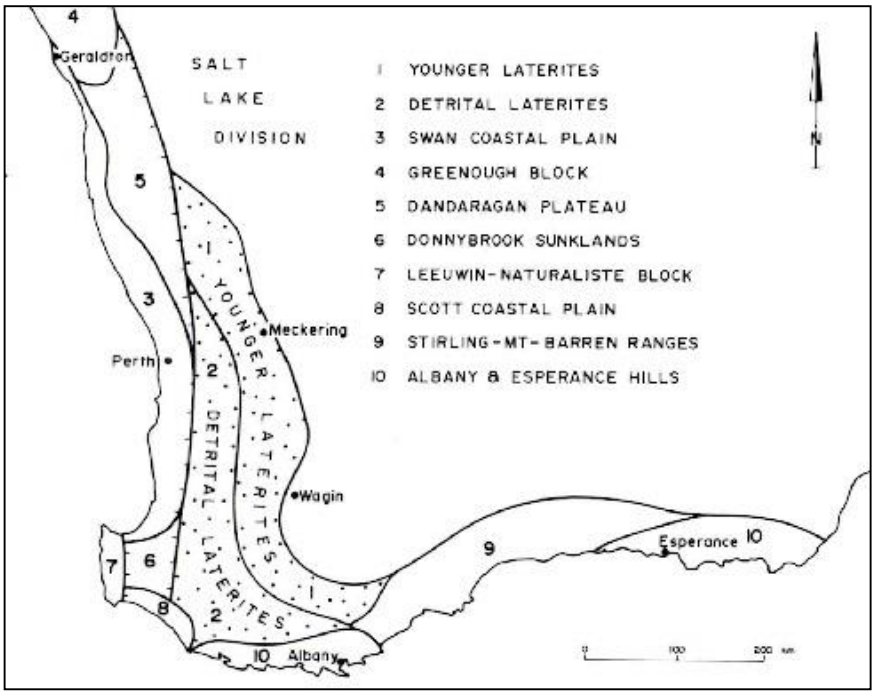
Summary of highest and lowest daily temperatures: Perth and regional centres Geraldton (North); Merredin (east); and Esperance (south-east)												
Record/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Highest daily: Perth Airport	46	47	44	37.7	35	28	26	28	32	38	41	45
Lowest daily: Perth Airport	20	20	16	13.9	12	9.4	11	9.9	13	12	14	15
Highest daily: Geraldton	44	40	N/R	37.6	N/R	N/R	23	25	29	35	38	41
Lowest daily: Geraldton:	27	26	N/R	24.5	N/R	N/R	19	18	19	19	23	25
Highest daily: Merredin	46	46	42	36.5	33	27	25	31	35	38	42	45
Lowest daily: Merredin	16	18	15	13.6	12	10	9.5	7.4	11	14	12	17
Highest daily: Esperance	47	47	44	40.1	35	26	28	32	34	41	43	45
Lowest daily: Esperance	17	18	17	12.7	9.3	11	9.6	11	12	11	12	16

Other than the IOD, the study area climate is also influenced by El Niño and La Niña events. During an El Niño event, the central and eastern tropical Pacific warms; whereas during a La Niña event the effects are reversed, cooling the same areas. The 2010–11 La Niña events bought much higher than average rainfall from July 2010 to March 2011 to most of Australia, but not the Southwest which had its driest year on record.

During El Niño events cloudiness is generally reduced which increases daytime temperatures; contrariwise, during La Niña events, bringing cooler than average temperature. This concludes discussion on the climate of the study area. A summary of the major landforms of the Southwest will now be presented.

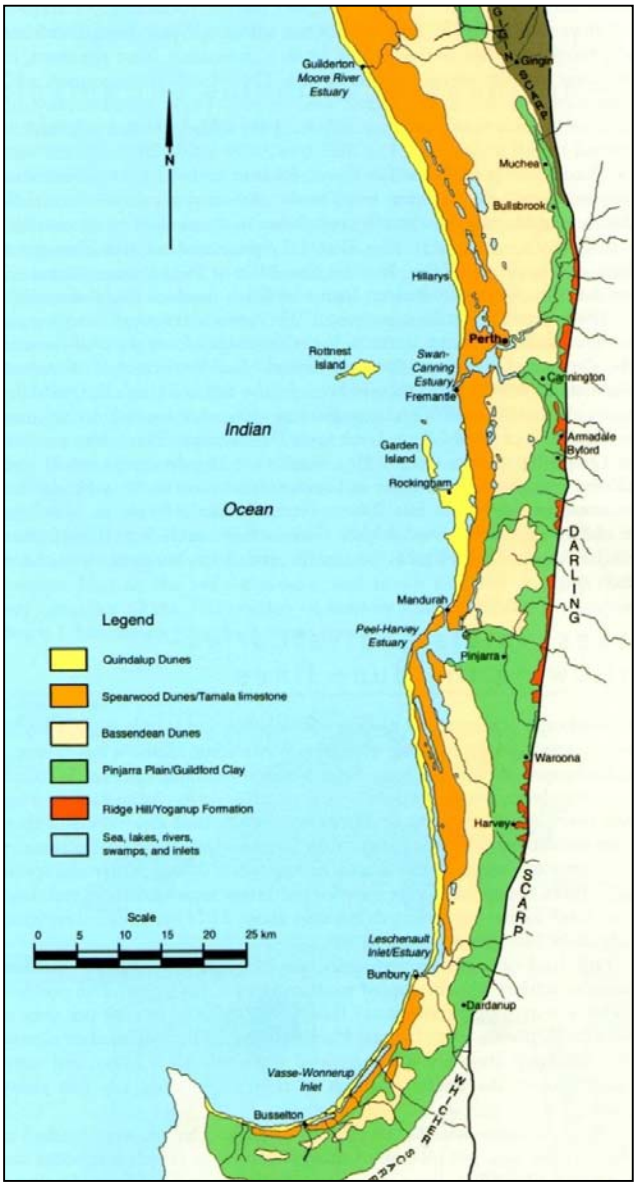
4.4 Landforms:

Many studies of the landforms of Western Australia have been undertaken (Clarke, 1926, 1935 ; Holmes, 1938, 1944; Jennings & Mabbutt, 1977; Jutson, 1914, 1934; Teakle & Gardner, 1938). Whilst a divergence in approach has seen variation in the number of regions, zones and divisions identified, each has recognised the Southwest as having distinctive geomorphic attributes (Map 4.2). Topographically the most significant feature of the region is the Darling Scarp which formed after Pliocene dislocation (2.58-5.33 Million Years Ago) (Ma). Running north-south from Muchea to Donnybrook (Gentilli, 1979) it extends eastward to Mount Bakewell, near York with its highest point at Mount Cook, near Jarrahdale (582m).



Map 4.2: Geomorphic regions of the Study Area (Southwestern Australia)
(Gentilli, 1979, p. 82)

Geologically the scarp signals the break between ancient granite rocks of the Yilgarn Block to the east, and younger sedimentary deposits to the west. To the west of the feature lies the Swan Coastal Belt, as described by Gentilli and Fairbridge (1951), sub-divisible into the Swan Coastal Plain, Greenough Block and Dandaragan Plateau. Of the three features, the Swan Coastal Plain (SCP) is the largest. Averaging about 30km across, it covers the area from the head of the scarp near Muchea, southward, terminating at the Collie-Naturaliste Scarp. For the most it is covered by Quaternary fluvial and aeolian sediments laid down in a series of zones that run almost parallel to the coastline. These deposits have been classified into five geomorphic features (McArthur & Bettenay, 1960): The Ridge Hill Shelf; Pinjarra Plain; Bassendean Dunes; Spearwood Dunes; and Quindalup Dunes(Map 4.3).



Map 4.3: Landforms and surface geology of the lower Perth Basin
(Adapted from Seddon, 1972 & Davidson, 1995 in Brearley, 2005, p. 7)

The linear configuration of deposits follows most of the Plain, although the northern end has more extensive sand dunes. Southward, at the bottom of the Peel Inlet, there are wide alluvial deposits. Each of the geomorphic elements identified display distinctive characteristics. For a detailed accounts of these refer to either Pilgrim (1979) or Davidson (1995).

Further south is the Donnybrook Sunklands or Blackwood Plateau (Brearley, 2005), Leeuwin-Naturaliste Ridge and Scott Coastal Plain. Nestled between the Darling and Dunsborough Faults they are comprised of sedimentary rock deposits forming rolling hills to a maximum height of approximately 150m. Westward lies the Leeuwin-Naturaliste Ridge which is starkly contrasted to the low-lying topographic relief of the Donnybrook Sunklands. The Ridge presents a "rugged coastline of gneiss and limestone promontories" (Gentilli, 1979, p. 85).

Further south, between the mouth of the Blackwood River and Point d'Entrecasteaux, drainage has been hindered by the dunes which has resulted in the formation of the low-lying swamps and wetlands of the Scott Coastal Plain. The features of the Plain are strongly contrasted to the craggy Stirling and Mount Barren Ranges.

The Stirling Range and Mount Barren Range are formed of slates and schists aligned in one direction due to deformation stresses. The hills rise sharply against the adjacent sandstone plain. The highest point, Bluff Knoll (1095m) is in the Stirling Ranges. The Mount Barren Ranges, which stretch from Hopetoun to east of Bremer Bay, formed as a result of folding and faulting around 1100 and 1400Million Years (Ma).

The Albany-Fraser Province, further south is younger, formed 11-1800Ma. They are comprised of the same sediments as the Mount Barren Group, with occasional pockets of granitic gneiss evident along the coastline from Bremer Bay to Point Charles. The Plantagenet Group, which is exposed along all major river lines, is younger still, having been formed in warm waters near sea level between 40-50Ma.

The Albany and Esperance Hills differ somewhat, consisting of granite and gneiss, the latter, a coarse-grained metamorphic rock displaying light and dark mineral elements separated into visible bands. The Porongurup Ranges near Mount Barker are a good example of such. It has also manifested as rugged coastal formations.

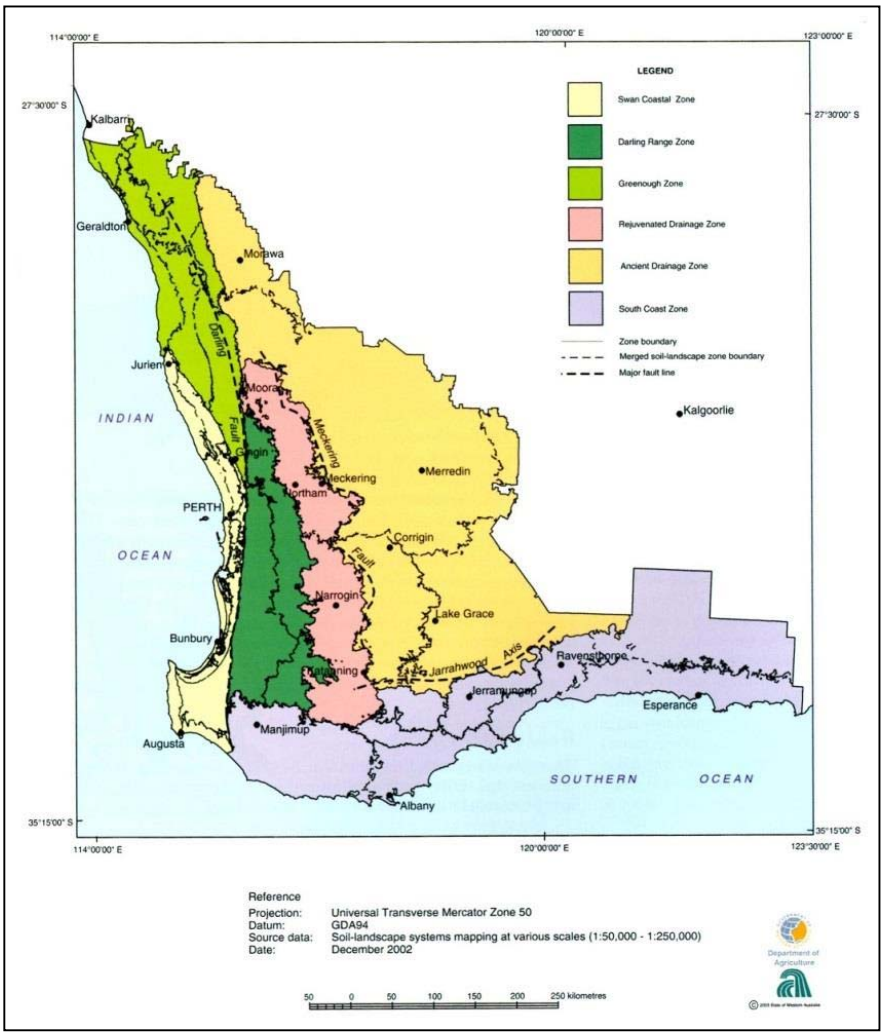
This concludes discussion on the major landforms of the study area. The next aspect of the physiography of the region to be examined is the hydrology of the region.

4.5 Hydrology:

The following summary of features related to the hydrology of the study area is principally referenced to Earnest Hodgkin's Swanland: Estuaries and Coastal Lagoons of *South-western Australia* (2005) which provides a detailed account of the features included in the discussion. As discussion is lengthy, it will be presented under separate title, commencing with drainage; estuarine systems and rivers; lakes and wetlands and to close; groundwater resources.

4.5.1 Drainage:

The first aspect of the hydrology of the study area to be discussed is the drainage system. Based on soil-landscape features, six zones have been identified: Swan Coastal; Darling Range; Greenough; Rejuvenated Drainage; Ancient Drainage; and South Coast (Map 4.4). The discussion commences here, as the soils and geology of each zone are associated to the rivers and estuarine systems contained within (Brearley, 2005, p. 19-22).



Map 4.4: Southwest Drainage Zones
(Adapted from Brearley, 2005, p. 20)

The Swan Coastal Zone lies west of the Darling Fault. It extends south from the Dandaragan Plateau to take in the Swan Coastal Plain; Donnybrook Sunklands /Blackwood Plateau; Leeuwin-Naturaliste Block and Scott Coastal (River) Plain. The rivers that traverse it flow over flat coastal areas. Its narrow northern sector has short, seaward flowing rivers loaded with alluvial sediment. Further south, seaward flowing rivers originate from the Leeuwin Ridge, west of Nannup and the Darling Fault; cutting through steep sided valleys, to feed the Blackwood Plateau.

The adjacent Darling Range Zone does not support any major rivers but is drained by lesser tributaries that generally only flow after high winter rainfalls. The riven soils of the zone are comprised of laterite, granite and gneiss which are overlaid on a granite base which causes water flow to rapidly drain away.

The zone abutting the northern perimeter of the study area is the Greenough Zone within which lies the 'Hutt to Irwin Drainage Area'. This drains several large water-ways including the Chapman, Greenough and Irwin Rivers (Brearley, 2005, p. 273). Each is awash with alluvial sediments carried from their inland origins.

Lands within the Rejuvenated Drainage Zone were first formed in the Eocene and later modified during the Miocene and early Pliocene eras as a result of uplift along the Darling Range. The zone is characterised by more deeply-cut rivers than those east of the Meckering Fault Line. Its associated streams flow most years. The soils of the zone are mainly comprised of colluvium and metamorphic rock.

The Ancient Drainage Zone can be traced back to the Eocene era. It is comprised of remnant river systems that once flowed across Gondwana. These drain to the south then track north-northwest along underlying rocks. Some sections were isolated by the rising up of the south end of the old Plateau around 43Ma. There are three sub-areas: northern, eastern and south-western, each with different underlying formations. It is mainly undulating plain over-laid on weathered granite. It features inland salt lakes as a result of poor drainage and low relief. Some of the longest rivers of the Southwest; the Moore, Avon and Blackwood drain from the zone along with several lesser rivers near the coast, southeast of Albany.

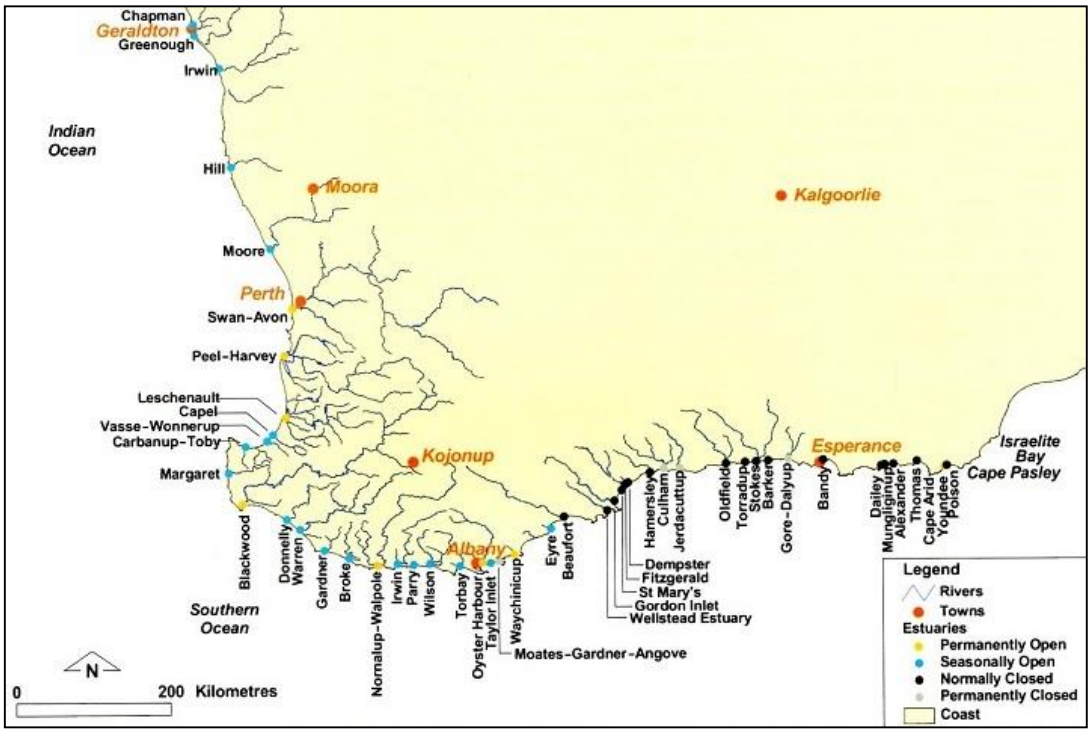
The South Coast Zone contains a number of rivers that are short, deep and south flowing. Uplift along its edges can be traced to the separation of Gondwana from Antarctica which caused older southward flowing rivers to truncate and reverse.

4.5.2 Estuarine Systems and Rivers:

The rivers of the Southwest are unlike others in the world, shaped by their ancient geological history. They do not spill from high peaks to traverse flat plains, but rather, originate in flat landscapes remnant of Gondwana, and rejuvenate closer to the coast.

The rifting of Antarctica caused new rivers to form, such as the Swan and the Frankland, which captured the ancient rivers. Sediment accumulated in areas of low relief and these broad inland *paleochannels* of the ancient rivers, such as the Moore and Avon, were occupied by salt lakes. Following heavy rainfall, these saline lakes spill into freshwater streams, sometimes with dire effects on the landscape they cross and the estuaries they spill into.

According to several reports (Brearley, 2005; Hodgkin & Hesp, 1998; Pen, 1999), there are 38 rivers; 40 major creeks and 180 lesser streams between Murchison River and Cape Arid, near Esperance. Of these only the Murchison, Hutt and Bowes Rivers and five lesser streams east of Esperance fall outside the study area parameters. Each drain into an estuary categorised as either: permanently or seasonally open or normally or permanently closed (Map 4.5).



Map 4.5: Geraldton to Cape Pasley Estuaries and Rivers
(Adapted from Brearley, 2005)

Permanently open estuaries spill major rivers such as the Swan-Avon; Peel-Harvey; Leschenault; Blackwood and Nornalup-Walpole systems, as well as the lesser Waychinicup River. Seasonally open estuaries include the Irwin, Chapman, Hill, Moore and Greenough River estuaries north of Perth; and the Capel, Vasse-Wonnerup, Carbanup-Toby, Margaret, Donnelly, Warren, Gardner, Broke, Irwin, Parry, Wilson, Torbay, Taylor Inlet, and Eyre River estuaries to the south. Of the remaining estuaries, situated between Albany and Esperance; 11 are classified as normally closed; and four; permanently closed. The discussion now proceeds to river and estuarine systems of the study area, in a north-south sequence, commencing with the largest of the northern rivers, the Greenough River.

The Greenough Rivers originates inland in the Yilgarn Plateau. It cuts south-westerly through deep valleys to cross the southern edge of the Victoria Plateau. Here it sweeps north-west across a flood-plain situated behind coastal dunes. From here it flows into the fertile soils of the Greenough Flats to enter the sea at Cape Burney. Its waters have been described as " turbid, laden with sediment and eutrophic" (Brearley, 2005, p. 283). Some reports suggest migrating waders no longer utilise the site as worm and prawn populations have diminished.

Discussion now moves further south to the Swan Coastal Plain, to the Swan River system (Brearley, 2005, pages 69-152). The estuary of the Swan sits in a river valley flooded by seawater *circa* 6000 years ago, although salt lakes of the Yilgarn Plateau and deposits in the Kings Park Shale contain elements from ancient eras. The Swan Estuary spills the Swan-Avon and Swan-Canning River systems, with a combined catchment area of 121 000km^2. This is mainly comprised of the sub-catchments of the Avon, Yilgarn and Lockhart areas. However most of its flow comes from the 2 117km^2 area of high rainfall catchment near the Darling Ranges. The Swan estuary extends 60km from Fremantle, terminating at Ellen Brook; and 6km up the Canning River, terminating at Kent Street Weir.

The Swan is fed by the Avon River which originates about 200km inland (its catchment area is larger than Tasmania (Water and Rivers Commission, 1999). The physical attributes of the river have been 'trained', to straighten and deepen it which has flooded most of the pools that run alongside it. At the base of the Scarp several tributaries converge, including the Helena River. The Helena River feeds Mundaring Weir, which supplies the Coolgardie-Kalgoorlie pipeline which is the major water supply to settlements of the Wheatbelt and Goldfields.

The lesser Canning River also feeds the Swan River, joining at Riverton. The Canning descends the Darling Plateau at Kelmscott along with several tributaries. It has been dammed, as have several larger tributaries, which has reduced water flow. A weir at Kent Street traps freshwater and inhibits salt water intake upstream.

Southward, 80km from Perth is the Mandurah the Peel-Harvey System (Brearley, 2005, pages 153-210). The Peel Estuary sits between the Spearwood and Bassendean Dunes; the Harvey Estuary, a dip between dunes of the Spearwood system. Its natural drainage was a narrow 5km channel with poor tidal flow. This was problematic as the system drains three major waterways: the Serpentine, Murray and Harvey Rivers. The Murray is the largest, taking in the Hotham and Williams Rivers that originate 150km inland near Narrogin. Near the coast, the Murray, Serpentine and North and South Dandalup Rivers flow into swamps and wetlands on the Swan Coastal Plain (which have been extensively cleared since European settlement). The Serpentine has been dammed for drinking water. Water flow is seasonal, with 90% reaching the estuary between May and October.

Algal blooms are common due to high levels of phosphorus entering the waterways from surrounding farmlands which were not adequately flushed due to poor water flow through the narrow natural channel. To remedy this, the Dawesville Channel was constructed. At 2.5km long, 200m wide; 6.5m deep (ocean end) and 4.5m deep (Harvey Estuary end) the channel cuts through tidal flats into deep water to maximise flushing.

Further south is the Leschenault Inlet and estuaries of Geographe Bay (Brearley, 2005, pages 211-254). The Leschenault Inlet is situated between old dune lines in an inter-barrier depression. It drains the Collie-Brunswick and Preston-Ferguson rivers. The elongated estuarine lagoon runs parallel to the coast, separated by sand dunes of the Quindalup System. It is bordered by sand flats but the surrounding landscape supports a range of habitat types.

South of Bunbury, the coast curves westward to take in Geographe Bay and Cape Naturaliste, including the Leeuwin Naturaliste Ridge. The rivers within are short, originating at the edge of the Darling and Whicher Ranges. They traverse the coastal plain to Geographe Bay and spill into the estuaries of the Vasse-Wonnerup and Carbanup-Toby systems. The area has been extensively cleared and modified including the addition of manufactured drains and channels to assist drainage.

The Vasse-Wonnerup Estuaries are fed by the Ludlow; Abba; Sabina and Vasse rivers. In winter, the wetland that connects via the Wonnerup Inlet extends to take in the coastal dunes and older Spearwood Dunes. In 1908 floodgates were installed to slow the flow of fresh water out and prevent sea water entering. However, the system has since been extensively modified and most rivers and manufactured drains now flow directly to the sea. Other areas hold floodwaters to trap freshwater and revegetate once saline areas. Nutrient loading remains a major problem with the area identified as the "the most grossly enriched major wetland system known in Western Australia" (McAlpine, Spice, & Humphries, 1989).

The next major estuarine system to further south is the Hardy Inlet and estuaries of the Naturaliste-Leeuwin Ridge (Brearley, 2005, pages 309-336). Here the coastal plain is narrow and most freshwater sources are short creeks and rivers. Margaret River is the only exception, which drains parts of the Blackwood Plateau. At Hardy Inlet, the Scott and Blackwood Rivers spill into the Southern Ocean.

The Blackwood River, at 330km, is the second longest river in the study area. It originates at Quelarup 210km south-southeast of Perth in the Yilgarn Plateau, within the Ancient Drainage Zone. It has 41 tributaries (Water Corporation of Western Australia, 2004) and the second largest catchment area in the Southwest, 28 000km^2 (the Swan-Avon system is the largest) (Brearley, 2005). Since European settlement approximately 85 % of its catchment has been cleared for agriculture (Berti, 2002). Parts of the river are seasonal with most of the 600mm annual rainfall falling between June-August.

The upper catchment crosses sandy undulating valleys, interspersed with salt lakes. The gradient is low, drainage poor and evaporation high; causing the river and its tributaries to flow infrequently. The middle section of the catchment, to the west of the Meckering Fault flows into U-shaped valleys, also of a low gradient and poor drainage. Flow is seasonal, drying out to brackish pools in summer. On reaching the Darling Range Zone, the valleys sharpen, and granite cliffs direct its course.

The lower catchment west of the Darling Fault crosses the Blackwood Plateau (Donnybrook Sunklands). This area received higher rainfalls (1000mm/annum). At Nannup, tributaries flow through steep-sided valleys from pristine forested catchments. At times they are the only permanent water when the Blackwood seasonally reduces or ceases to flow. Below the convergence of the Blackwood-Arthur Rivers it becomes permanent, fed by waters from the Perth Basin.

The next segment describes the estuaries situated between Hardy Inlet and Wilson Inlet (Brearley, 2005, pages 337-396). These estuaries are fed by substantial rivers that drain the ancient, dry interior; as well as their lesser tributaries and soaks. It is the wettest section of the coast, and the weather, in combination with river flows and estuarine conditions, impact the plants, animals and ecological systems within.

Each inlet of this section of the coast has its own distinctive characteristics: Broke Inlet is surrounded by heavily wooded catchment; whilst Wilson, Irwin and Parry Inlets are bounded by cultivated farmlands, causing salient and eutrophic conditions that feed extensive algal blooms and aquatic plant growth (seaweed). The estuaries vary in size, with Broke and Walpole-Nornalup estuaries being the largest; and the Irwin and Parry systems are smaller, shallower and at times, hypersaline.

The upper catchments of the rivers of the section originate in the ancient Yilgarn; and the overflow of salt lakes into the water ways occurs after heavy rains. The rivers of the area include the Warren, Donnelly, Frankland-Gordon and Kent Rivers. As they flow seaward they enter the ‘Rejuvenated Drainage Zone’, to cross the Ravensthorpe Ramp, a 40-80km strip that slopes toward the Southern Ocean, promoting deepening and widening of the river ways.

The orientation of the dunes significantly influence the WSW-ENE direction the lower reaches of the river channels, and Broke Inlet intake. The beaches between Cape Beaufort and Point D’Entrecasteaux face either south or south-west, directly into prevailing winds and swell, backed by high coastal dunes, which in parts have consolidated into limestone cliffs. The Nornalup Inlet however, is shielded by granite cliffs that protect the estuary entrance from the pounding swell and buffeting winds.

The lesser Donnelly, Warren and Gardner rivers flow into 'riverine' estuaries on the western side of the Scott Coastal Plain. Each lacks a basin or lagoon, although the Donnelly has a broad-water area where it terminates. They are not truly estuarine, as the marine influence is low; and have been described as 'transitory' estuaries.

Further south is the Walpole-Nornalup estuary in heavily forested area dominated by giant trees. This area receives the highest rainfall in the study area (1300mm/annum), which reduces by half in its northern catchment. It spills the longest, largest river of the Southwest, the 400km Frankland-Gordon System. It also spills Deep River, one of several 'Wild Rivers' of the Southwest, so called as they retain mostly pristine vegetation. The Frankland, which originates inland, spills saline waters, whilst the Deep and other rivers spill freshwater into the system.

The nearby Irwin and Parry Inlets are much smaller: The Irwin spills the Kent and Bow Rivers and several creeks. The Parry Inlet spills only one river and several drains. Both are nutrient loaded due to fertilisers entering from surrounding agricultural lands. Whilst Nitrogen levels are similar to other inlets of the area; the level of phosphorus has been likened to that of the Vasse-Wonnerup estuary.

The Wilson Inlet near Denmark is set on a narrow coastal plain between the Nullaki Peninsula and surrounding granite hills. It spills the Hay River on its eastern side; and the Denmark River on its northern shore. Both traverse agricultural areas and are saline. But lesser rivers and drains spill freshwater from forested catchment.

Within the southernmost waterways of the study area, from Albany to Esperance (Brearley, 2005, pages 397 - 496), the estuaries are relatively young (like the Swan Estuary at around 6000 years). However, the lands they drain are ancient (around 1 000 million years old). The area between Knapp Head, Torbay Head and Bald Head on the Flinders Peninsula form the southernmost point of WA and protect the majestic King George Sound in Albany. Princess Royal Harbour spills no major rivers and is fed by rainwater and seepage. Oyster Harbour is the most protected estuary of the study area, whilst Two Peoples Bay, to the east, captures Gardner and Angove Lakes, Goodga River, swamps and wetlands.

At the northern end of Two Peoples Bay, are King Creek and Normans Inlet. Normans occupies a narrow valley of the Mount Manypeaks Range. The southward facing range forms the gorge of the Waychinicup Estuary. The geology of the estuary is different from most other south coast systems which spill onto low-lying flats, and the rocky headland maintains a permanent opening to the sea.

The Waychinicup River originates near Manypeaks, flowing southward through the Manypeaks Ranges and taking in Waychinicup National Park. The river itself is not spectacular, but it feeds an ecologically significant site which hosts 1700 plant species (75 endemic) and several rare and endangered bird species.

These include the Noisy Scrub Bird (*Atrichornis clamosus*) (once thought extinct); Western Ground Parrot (*Pezoporus wallicus*); and Western Bristlebird (*Dasyornis longirostris*); as well as endangered Carnaby's Black Cockatoo (*Calyptorhynchus latirostris*) (South Coast Regional Assessment Panel and the South Coast Regional Initiative Planning Team, 1996).

The final estuaries to be explored are those that lie to the east of Albany. These systems rely heavily on summer rains due to the high levels of evaporation which sometimes dries the estuaries out, leaving hypersaline, silt laden pools. Most estuaries of the region are classified as 'normally closed' as they rarely open to the sea; usually only after prolonged and drenching rains. The systems are small and shallow. The Beaufort, Hamersley, Stokes and Oldfield Estuaries are usually barred by 2-3metre sand bars. The Fitzgerald and Saint Mary Estuaries are especially shallow and open less frequently. The Fitzgerald, like the Waychinicup River, feeds an ecologically significant site.

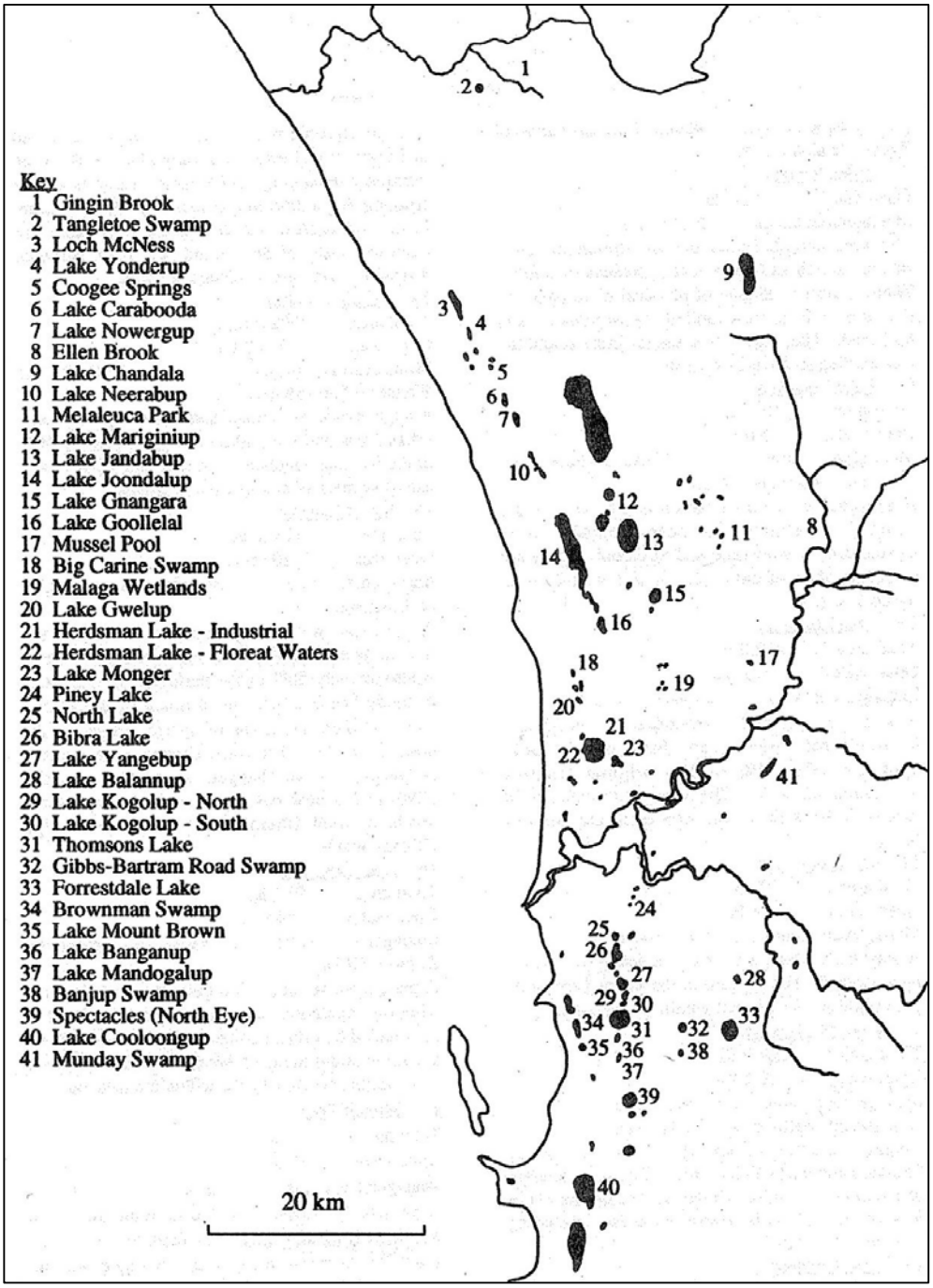
The catchment of the Fitzgerald River takes in approximately 329, 039ha and includes the Fitzgerald River National Park (FRNP), a designated 'Biosphere Reserve' under the auspices of the UNESCO 'Man and the Biosphere' Programme. Its inclusion was designed to protect its relatively pristine habitat and biological diversity (DEC, 2012a). The area supports more vertebrate species than any other National Park or reserve in the Southwest. It also hosts rare avifauna including Western Bristlebird; Western Whipbird (*Psophodes nigrogularis*); Western Ground Parrot and Carnaby's Cockatoo (DEC2012a).

Other rivers that flow through the FRNP include the Gairdner, Hamersley and Phillips Rivers. Each flow roughly north-west to south-east through and their catchments fall at least in part in agricultural lands. Lesser rivers within FRNP, such as the St Mary and Dempster Rivers, as well as smaller streams are seasonal, with major flows restricted to winter and spring. The Dempster River catchment, which is completely contained within FRNP, is totally uncleared and has pedestrian access only. This is an important factor in limiting outbreaks of Dieback; a plant disease caused by the water mould *Phytophthora cinnamomi*; it presents a dire threat to ecosystems of the entire Southwest region. This concludes discussion of the river and estuarine systems of the study area.

4.5.3 Lakes and Wetlands:

Due to the large numbers of lake and wetland features (Map 4.6) discussion is limited to those possessing natural heritage or particular ecological values. It is important to note that prior to European settlement almost 25% of the Swan Coastal Plain was 'wetland', defined as:

> …areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth to which at low tide does not exceed six metres (Water and Rivers Commission, 2001, p. 1)



Map 4.6: Wetlands of the Swan Coastal Plain
(Source: Davis *et al*., 1993)

Not all such sites have retained significant ecological values due to the impact of concentrated urban and agricultural development. Most have been filled, developed or cleared, with only 20% of SCP wetlands remaining. Of these only 15% retain sufficient ecological values to qualify as conservation category wetlands.

Whilst there are a number of wetlands in the north-western sector of the study area discussion commences with the Wanneroo Wetlands chain, a linear system of lakes. Lake Joondalup is the largest lake of the system and is a major roost and rookery for Australian White Ibis (*Threskiornis molucca*) and Straw-necked Ibis (*T. spinicollis*) (Bekle, 1982). It also hosts substantial populations of Cormorants, Heron, Spoonbill, Egrets and Darters, which also roost there.

The Wanneroo Wetland Chain, including Lake Joondalup been hugely impacted by human settlement which is evidenced in the surrounds: remnant horticultural holdings, intensive residential development and parklands. Despite such intense modification, they retain significant ecological values, providing food sources, roosting and nesting sites.

Whilst there are numerous wetlands and lakes along the SCP, most which parallel the interdunal boundaries; discussion here is limited to just Thomsons Lake, Forrestdale Lake and Becher Point Wetlands. Each is a 'globally significant' Ramsar site, protected under 'The Convention on Wetlands of International Importance', a treaty that supports national action and international cooperation for the conservation and protection of wetlands. First adopted in Ramsar, Iran in 1971 it now has member countries across the globe. There are 12 Ramsar sites in WA (eight in the study area). The following summaries are based on information sourced from the Department of Conservation website, *Ramsar Wetlands* link (DEC, 2012b).

Thomsons Lake, near the southern suburb of Success, is bordered by intensive urban residential development and lies in close proximity to an airport. The lake occupies a depression between the Bassendean and Spearwood Dunes. It has had sediment dredged from it dated 30 000 - 40 000 years old, making it the oldest wetland site in the State (DEC, 2012b) (Plate 4.1).

Plate 4.1: Ramsar listed wetland: Thomsons Lake
(Walk GPS, 2003)

Further inland sits Forrestdale Lake in the suburb of its namesake; a once semi-rural area, it has recently been intensively developed. The lake is located on the eastern edge of the Bassendean Dunes in a deflation basin. It is edged by low sand ridges. Its north-eastern margin is marked by a rocky outcrop of sandstone.

Both sites have been identified as the best remaining examples of brackish, seasonal lakes with sedgeland fringes, typical of the SCP. In a regional context, they are critical migration stop-over locations, providing semi-permanent drought refuge areas, and breeding grounds for water birds. Both sites, located close to landfill sites, also support substantial populations of Australian White Ibis.

They are ecologically significant pockets of wetland and bushland habitat in an area largely devoid of native vegetation. The subdivisions that surround them have been divided into small allotments, the houses are closely abutted, many with gardens featuring exotic palms and other non-native plants. The sites provide a freshwater source for birds and other wildlife including bird species protected by the Japan-Australia Migratory Bird Agreement (JAMBA) and China-Australia Migratory Bird Agreement (CAMBA).

To the west of Thomsons Lake, near Rockingham, lie the Becher Point Wetlands, situated within the Quindalup Dunes. The site runs approximately parallel to the coast and is comprised of chains of small linear, ovoid or irregular shaped swamps, grouped and separated by sand ridges. In total about 200 small wetlands are preserved between Becher Point and the Perth-Mandurah Road. It is the youngest wetland system of the SCP and is listed as a threatened ecological community. This wetland type is rare in the study area and globally, its landforms and geomorphology are in good condition and lay within a protected area. It is fed by groundwater from the Perth Basin and remains inundated. It is an important summer refuge.

Discussion now moves to regional lakes and wetlands, firstly, to Lake Toolibin, which is situated approximately 200kms southeast of Perth, in the Wheatbelt. This perched freshwater lake is fed by the Upper Blackwood River. It lies in a low rainfall area and experiences extreme evaporation which causes it to seasonally diminish to a brackish-wooded pool. When it is full, it overflows into surrounding wetlands and the headwaters of the Arthur River (
Plate 4.2).

It is fringed by rich habitat and provides a haven for numerous plants and animals. It is an ecologically significant site as most other remaining regional wetlands that supported similar vegetation complexes and ecosystems have been cleared for agriculture. Most inland lakes are highly saline and Lake Toolibin is the only major lake in the catchment not completely saline (Threatened Species Network, 2008). It is affected by dryland salinity, as is much of the Wheatbelt landscape.

Plate 4.2: Ramsar listed wetland: Lake Toolibin
(Department of the Environment, 2008)

Further south, in the wet, forested hinterlands lays the Muir-Byenup System. Lake Muir is situated 55km east-south-east of Manjimup although the system also takes in Lake Byenup, the Tordit-Gurrup Lagoons, as well as Poorginup, Neeranup, Coorimup and Wimbalup Swamps. This series of inter-connected lakes and swamps range from saline to fresh, and contain permanent and seasonal waters. The site hosts rare floristic varieties including three types of 'vulnerable' wetland orchids. A total of 649 indigenous flora taxa have been identified within the system. The adjacent forests also host the only identified populations of Australian Lilaeopsis (*Lilaeopsis polyantha*) in the state (DEC, 2003f) (Plate 4.3).

Plate 4.3: Ramsar listed wetland: Lake Muir
(Department of the Environment, 2012)

The final Ramsar sites to be presented for discussion are Lake Warden and Lake Gore located in the Shire of Esperance. Lake Warden provides an excellent example of saline coastal lakes typical of the south coast of WA, although in excess of 80% of its 171 000ha catchment is cleared. The hydrology of the system is complex, incorporating seven main lakes and over 90 satellite lakes fed by groundwater and surface inflows (Brearley, 2005). Of the 59 waterbird species identified utilising the site, 17 are listed under the JAMBA and CAMBA treaties.

The Lake Gore site also takes in overflow wetlands , a series of inter-connected lakes and swamps that are intermittently inundated and near-permanently saline (Moore, 1988). Its open water is a drought refuge for waterbirds and ducks and a major moult site for Australian Shelduck. Waterbird populations at times reach almost 30 000 and are in the tens of thousands most years. It is affected by algal blooms due to the extensive use of fertilisers within the cleared catchment. The water turned naturally saline 5-6000 years ago, but salinity within the catchment has increased markedly causing the riparian vegetation to die off. The presence of dead trees within the paperbark woodlands suggests damage from lengthy inundation due to increased flows arising from clearance of the catchment for agriculture (Plate 4.4).

Plate 4.4: Ramsar listed wetland: Lake Gore
(Google Images, 2008)

The other two Ramsar listed sites within the study area are the Peel-Yalgorup Wetlands, linked to the Peel-Harvey Inlets as previously discussed; and the Vasse-Wonnerup Wetlands, which are similarly linked to the estuarine system of the same name. Neither site is presented for detailed discussion in this segment.

4.5.4 Groundwater Resources:

The role of groundwater in terms of the present study is limited. These main groundwater reserves are found in sediments of the Northern and Central Perth Basins; the Peel-Harvey Area; Southern Perth Basin; Collie Basin and Bremer Basin (near Albany). Along with surface water, each groundwater reservoir is a source for domestic water supply; irrigation for crops and pastures and industry.

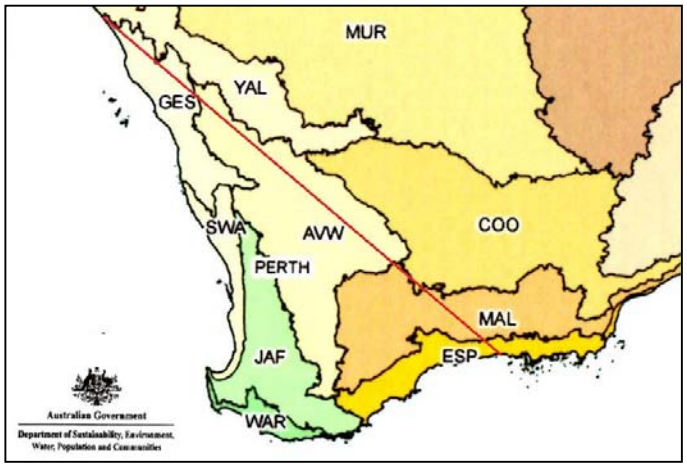
For further details, refer to *Groundwater Yields in South-west Western Australia* (CSIRO, 2009). For information about groundwater reserves for Esperance, refer to *Esperance Groundwater Area Water Management Plan* (Department of Water Western Australia, 2007).

4.6 Vegetation:

The first extensive review of native and non-native vascular plants throughout Western Australia was undertaken by East (1912) although subsequent appraisals have been carried out (Beard, 1969; 1990). The Southwest region has been consecutively defined as a distinct 'Botanical Province', and is said to contains over 7000 native vascular plants (species/subspecies); 49% of which are endemic and 2500 of which are of conservation concern (Hopper & Gioia, 2004).

It is comprised of several 'Botanical Districts', identified by Beard (1969; 1990) as: Irwin; Avon; Roe; Eyre and Darling (which included the sub-regions: Drummond, Dale, Menzies and Warren). The outlook is congruent with data contained in the *Census of Western Australian Plants* database (WA Herbarium 1998 to the present).

However these have since been revised and based on the 'Interim Biogeographic Regionalisation for Australia' framework (Version 7) (Davidson, 1995), the current botanical bioregions of the Southwestern Province are: Geraldton Sandplain - GES; Avon Wheatbelt - AVW; Swan Coastal Plain - SCP, Jarrah Forest - JAF, Warren – WAR, Mallee - MAL and Esperance Plains – ESP. The Geraldton Sandplains are also referred to as the 'Kwongan' the traditional name given by the Noongar people (Map 4.7).

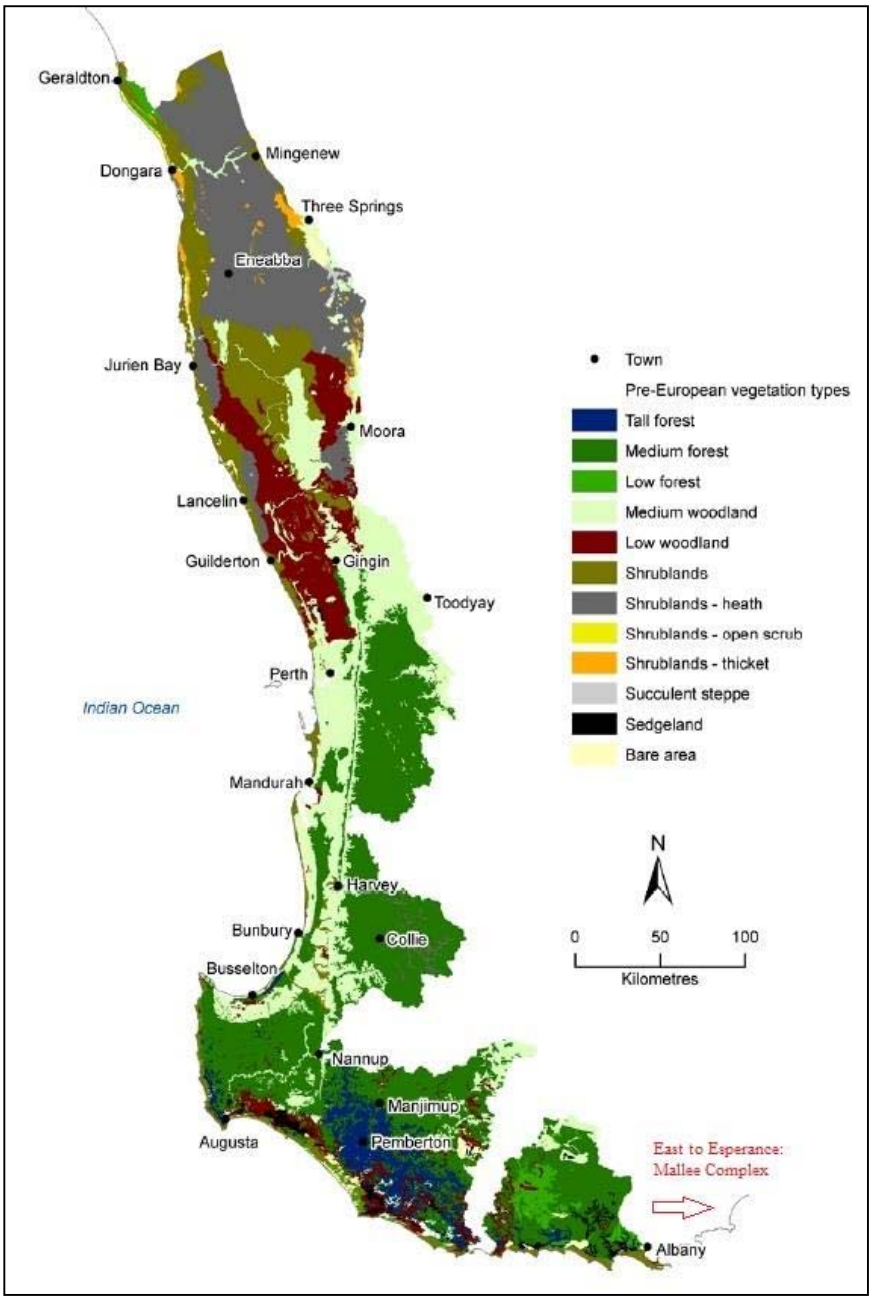


Map 4.7:Botanical Districts of Southwestern Australia
(Davidson, 1995)
(Exception to copyright: Section ss 40, 103C for Research or Study)

These updated boundaries are broadly compatible with Beard's earlier phytogeographic regions, the main difference being that some smaller sub-regions have been amalgamated. The extent of vegetation cover has altered significantly since European settlement. As previously stated, the region is synonymous with high levels of endemism impacted by habitat loss. A tabled summary of the area of each bioregion and the extent of lands cleared of native vegetation within each is shown below. A map of pre-European vegetation extents is also shown (Australian Natural Resource Atlas, 2009) (excluding Esperance/Mallee complexes) (Table 4.2 and Map 4.8).

Table 4.2: Southwest Bioregions Vegetation Extent Summary
(Adapted from Australian Natural Resource Atlas, 2009)

SOUTHWEST REGION: CLEARED / MODIFIED NATIVE VEGETATION EXTENTS		
Bioregion	**Area (ha)**	**% of total extent cleared**
GES - Geraldton Sandplains	1 921 976	48.4
AVW - Avon Wheatbelt	8 132 108	85.4
SWA - Swan Coastal Plain	915 752	60.5
JAF - Jarrah Forests	1 959 380	43.5
WAR - Warren	166 224	19.7
MAL - Mallee	3 389 464	45.8
ESP - Esperance Plains	1 402 020	48.2



Map 4.8: Pre-European Major Vegetation Complexes of the Southwest
(Adapted from CSIRO, 2009)

The synopses of the main vegetation complexes of each of the bioregions is based on the *Revision of the Interim Biogeographic Regionalisation of Australia* (Department Environment, 2000). Discussion begins with Geraldton Sandplains Bioregion.

The Geraldton Sandplains Bioregion [GES] area supports extensive proteaceous heaths and scrub-heaths rich in endemics. The rolling sandplains are underlain by laterite and supports mallees, *Banksia* and *Actinostrobus* interspersed with occasional York Gum (*E. loxophleba*). Acacia woodlands occur on alluvial plains and in drainage valleys whilst coastal sands and limestone areas host proteaceous heath (Plate 4.5).

Plate 4.5: Geraldton Sandplains Bioregion (Kwongan)
(Google Images, 2010)
(Exception to copyright: Section ss 40, 103C for Research or Study)

Further south is the Avon Wheatbelt Bioregion [AVW] which is located within the Yilgarn Craton. It has two sub-regions: the eastern sector is an undulating plain of low relief and ancient drainage interspersed with salt lake chains, although they only function following very wet winters. The residual laterite uplands and surrounding yellowish sandplains support proteaceous scrub-heaths, also rich in endemics such as Grevilleas, Hakeas, Eucalypts, Acacias, and Eriostemons (Plate 4.6).

The western section of the Avon Wheatbelt bioregion is also comprised of undulating slopes to low hills. The drainage is younger and contains streams and channels that flow most years. Laterite uplands and surrounding sandplains support proteaceous scrub-heaths rich in endemics. Surface slopes and valleys support woodlands of Wandoo (*Eucalyptus Wandoo*); York Gum, Jam (*Acacia acuminata*) and Casuarina.

Plate 4.6: Avon Wheatbelt Bioregion
(Marriot, 2008)

Continuing south is the Swan Coastal Plain Bioregion [SWA] which takes in the Dandaragan Plateau, Perth Coastal Plain and several offshore islands. It also encompasses Perth city and the metropolitan area. Its sandy soils are dominated by woodlands of *Banksia* and Tuart (*E. Gomphocephala*), with occasional sheoak on outwash plains. Paperbark (*Melaleuca rhaphiophylla*) grows in swampy areas (Plate 4.7).

Seasonal freshwater wetlands occur over alluvial river flats. Younger sands and limestone areas are predominantly overlaid by heath and/or Tuart woodlands; whilst *Banksia* and Jarrah-*Banksia* woodlands cover the older dune systems. Fine-textured outwash plains at the base of the Darling Scarp are extensive toward the south and were dominated by *A. obesa*-marri woodlands and *Melaleuca* shrublands. The north-east sector ascends and hosts mainly Jarrah woodland. The drier northern sector supports proteaceous heath and scrub-heath.

Plate 4.7: Swan Coastal Plain Bioregion
(Wallace, 2012)

South of the Swan Coastal Plain Bioregion is the Jarrah Forrest Bioregion [JAF] which is aptly named, for it is as it sounds, comprised of predominantly Jarrah (*E. Marginata*) and Marri (*E. calophylla*) forest over laterite gravels. Characteristics change on the eastern margins into clay soils with mainly Marri-Wandoo woodlands. Alluvial deposits in the southernmost sector support *Agonis* shrublands. The Jarrah forests and shrublands of the region are extremely species rich and support high levels of endemism (Plate 4.8)

It has two subregions: Northern and Southern. The Northern sector lays over granite and rocks capped by laterite. Occasional granite outcrops present as isolated hills with the elevation of the surrounding plateau constant at about 300m. The main vegetation complexes of the sub-region are Jarrah - Marri forest in the west; with Bullich (*E. magacarpa*) and Yarri or Blackbutt (*E. patens*) in the valleys. Wandoo woodlands cover the eastern sector. Extensive *Banksia* low woodlands occur over sandy areas. Profuse heath covers the granite rocks, providing an understory for the forests. Profuse woodlands extend into the north and east of the region.

The Southern sector of the Jarrah Forest Bioregion lies over a laterite plateau that broadens and slopes mildly toward the south coast. The crusted sands of the south-east portion are almost level; resulting in limited drainage. The run-off feeds a number of wetlands, including the Ramsar listed site, Lake Muir.

This area receives high rainfall and supports extensive Jarrah - Marri forest in its western sector. This graduates to Marri and Wandoo woodlands in the east of the sector. Areas of swamp in the south-east host Swamp Yate (*E. occidentalis)* and Paperbarks: The mesic nature of the bioregion is evident in its profuse forested woodland and near impenetrable understories.

Plate 4.8: Jarrah Forest Bioregion
(Oliver, 2008)

The Warren Bioregion [WAR] takes in the area occupying the coastal sandplain between Cape Naturaliste and Albany. It extends from the ocean to the edge of the Yilgarn Craton Plateau, approximated as the lands within ten kilometres of the coast. North of Point D'Entrecasteaux, however, it extends further inland to almost as far as Nannup and Manjimup. It is bounded to the north and east by the Jarrah forest. There are a number of towns within its boundaries, including Margaret River, Augusta, Pemberton, Walpole, Denmark and Albany (Beard & Sprenger, 1984) (Plate 4.9).

The region is comprised of divided, undulating landscapes of the Leeuwin Complex, Blackwood Plateau (Southern Perth Basin). It is broken up by the south-west section of the Yilgarn Craton and western sections of the Albany Orogen. The rich, loamy soils support Karri (*E. diversicolor*) forest; and rockier laterite areas support Jarrah-Marri forest. The leached sandy soils of depressions and plains support low Jarrah woodlands, paperbark and sedges. The marine dunes support groves of Western Australian Peppermint (*Agonis flexuosa*); *Banksia* woodlands and heaths

The Warren Bioregion also hosts the spectacular Red Tingle (*E. jacksonii*). This resistant, rough barked tree can survive for over 400 years, reach 75m in height, and possess a girth of up to 26m:, the largest base of all the eucalypts. The less majestic Yellow Tingle (*E.guilfoyle*) does not reach the same dimensions.

Plate 4.9: Warren Bioregion
(Amandak, 2008)

To the east is the Mallee Bioregion [MAL] which occupies the undulating, south-eastern section of the Yilgarn Craton. It lies in a low rainfall area and the vegetation complexes if the region reflects that. The area is comprised of two subregions: the Eastern and Western Mallee. The Eastern sector lies over clay and loam that displays occasional outcrops of kankar (layered calcium carbonate) as well as sandstone with intermittent salt pans.

The vegetation mosaic is predominantly mallee over areas of sandplain with samphire established around small salt lakes. Patchy woodlands and mallee cover the clay soils and Mallee with Boree (*Melaleuca pauperiflora*) covers clay-loam soils (Plate 4.10).

The Western Mallee has more elevated sites than the eastern sector. It is comprised predominantly clays and silts underlain by kankar. It displays outcrops of exposed granite surrounded by extensive sandplains with isolated uplands of laterite. Intermittent salt lake systems pool over a granite basement.

The Mallee communities continue to dominate most surfaces and *Eucalyptus* woodlands occupy areas of finer-textured soils. Scrub-heath covers sandy areas and areas of lateritic gravel. The vegetation complexes of the Mallee Bioregion extend into the Esperance Bioregion.

Plate 4.10: Mallee Bioregion
(Scames, 2010)

To the south of the Mallee Bioregion lays the Esperance Plains Bioregion [ESP]. This region is also divided into two subregions: Fitzgerald and Recherche. The Fitzgerald has irregular relief flattening out on sandplains nearer the coast. The plain has shallow and deep yellow sands, and shallow sands cover the range slopes (Plate 4.11).

Vegetation complexes of the Fitzgerald subregion includes scrub heath and mallee heath with occasional White Marlock (*E. tetragona*. On the coast dune scrub predominates with mallee woodlands in some areas. Yate and York Gum woodlands are established on alluvial soils; and Jarrah/Marri woodlands dominate the west. The granite and quartzite ranges are covered by herbfields and heaths rich in endemics. Woodlands of Black Marlock (*E. redunca*) and occasional Yellow Mallee (*E. incrassata*) occupy gullies.

The Recherche sub-region has similar relief to the Fitzgerald. It is comprised of coastal sandplains and dunes that overlay gneiss, granite and younger coastal limestone. Several granitic islands occur close to the shore of the region. Vegetation is mainly heaths, coastal dune scrubs, mallees, mallee-heaths and granite heaths.

Plate 4.11: Esperance Plains Bioregion
(Google Images, 2012)

This concludes discussion on the main vegetation complexes of the Southwest, the final aspect of the physical geography of the mainland areas of the study area to be presented.

Brief summaries of the geography of each of the islands that also feature in the study are now given.

4.7 Islands:

Only two of the three islands offshore from Fremantle feature in the study: Rottnest Island and Garden Island, as none of the focus species have been recorded on Carnac Island, "an exposed barren islet with low scrubby vegetation and few dense thickets" (Serventy, 1938 , p. 265). The general descriptions given below are taken from Serventy (1938), which although dated, were considered precise. The pre-metric figures have been converted and are shown first.

All of these islands display the same physical characteristics and vegetation of the coastal dunes of the mainland. They are composed of aeolian limestone, and support *Callitris* (Cyprus) and *Acacia* (Wattle) that form dense thickets; they lack tall timber, and have no Eucalypts. Rottnest differs from the other two as it has several salt lakes (isolated portions of the sea) and freshwater pools. The other islands have no open water, making conditions unfavourable for terrestrial birds.

Rottnest is about 1912ha (4,726 acres) and approximately 11.0km (7.0 miles) from east to west, and 4.0km (2.5 miles) maximum width from north to south. It is situated approximately 18km (11 miles) west by north half north from Fremantle (1938, p. 265).

Garden Island is 1129ha (2,790.5 acres) and approximately 10.5km (6.5 miles) from north to south, with an average width of just under a 1.6km (1.0 mile). The northern end is about 8.5km (5.25 miles) from the mainland and the south end about 2.0km (1.25 miles) from Point Peron. The northern extremity is almost 13km (8 miles) south-south-west of Fremantle (1938, p. 267).

The other islands that are mentioned in the study are situated off the southern and south-east coast of Western Australia and include Bald Island, Breaksea Island, Michaelmas Island and Chatham Island. The largest, Bald Island is 1.5km offshore from Cheynes Beach (Albany). Since 1964 it has been a World Conservation Union Category 'A' Class Nature Reserve. At $8km^2$, it is composed almost entirely of granite. It rises steeply from the ocean to height of about 300m (Department of Environment, 1998).

Breaksea Island is in King George Sound, 12km south-east of Albany. It is also a nature reserve and is registered as a national estate. It is just over $1.0km^2$ in area, three kilometres in length and 600 metres across at its widest part. The closest island in proximity is Michaelmas Island, 1.5km north (Department of Environment, 1998).

Michaelmas Island, also off King George Sound, is also a nature reserve and registered national estate. The island is almost 92ha in area. It has steep rocky shores with submerged reefs all along its northern southern and eastern sides in depths up to 30m and displays large granite boulders (Department of Environment, 1998).

Chatham Island is located on the southern coast approximately 1.0km offshore from D'Entrecasteaux National Park and 3kms offshore from Mandalay Beach. It is also a 1A Nature reserve, comprised of 106ha (Department of Environment, 1998).

To close the chapter outlining the study area discussion now turns toward reviewing the possession history, current population levels and regional growth. The final aspect to be presented relates to the development of transport networks, focusing on regional road and rail systems. These transport networks are especially important as they cut pathways through the study area that acted as transport vectors for wildlife and influenced the spread of the focus species.

4.8 Possession, Population and Passage:

Prior to European settlement Western Australia was inhabited by Aborigines that "lived in ecological balance with the land" (Gentilli, 1979, p. 6). Its peoples belonged to numerous distinct language families. Aborigines of the Southwest belong to the 'Nyungar' (Nyungah or Noongar) language group which incorporates peoples from a number of different language groups. The arrival of Europeans dispossessed many Aboriginal people, their lands either "overrun or taken from them" (Jarvis, 1986, p. 37). Many moved into towns and settlements but retained ties to the traditional lands.

The Southwest contains many sites of cultural and historical significance, some considered "a key to Aboriginal activity over tens of thousands of years" (Jarvis, 1986, p. 37). Traditionally, the Nyungar lived according to six seasons unique to the Southwest region. The arrival of each season influenced the choice of location for camping and the activities undertaken. They lived as hunter-gatherers, taking what was needed for subsistence and trade. The ecological impacts of their activities were restricted to killing game; collecting bird and waterfowl eggs; and the use of fire, as controlled burns, to aid hunting and assist bush regrowth. However, this changed markedly with the arrival of Europeans.

Early expeditions to Western Australia were carried out in the sixteenth century, but it was not until the following century that the coastline was charted by Dutch traders. Early reports describe the area as unsuitable for settlement, possessing a coastline of reefs and shoals and a hot, arid interior, a place whereby "water supplies were unreliable and Aborigines were not only an unlikely source of useful labour but also the absence of jewellery and precious metals on their bodies suggested none existed" (Jarvis, 1986, p. 39)

The settlement of the Swan River Colony was "almost accidental and largely unplanned (Statham, 1981, p. 181). The site was first suggested by Captain James Stirling as an alternative defensive position to King George Sound (Albany) to protect British interests in the region against French acquisition. However, after surveying the area with a government botanist, he recommended the site as a new settlement as "the region had all the necessary attributes of a successful agricultural colony" (1981, p. 182). The proposal was initially rejected but the British government later agreed to the establishment of a free colony, to be opened to investors and retired civil servants.

The settlement was formally annexed to Britain in 1829. Soon after it was discovered that the initial appraisal of generally fertile soils was erroneous, and the region was sparsely vegetated, and "typified by sands and swampy leached soils" (1981, p. 184). The rich alluvials soils were limited to narrow strips along river banks and at the base of the Darling Range; with the most productive areas more than 32km from the coast. Two townsites were founded, the portside town of Fremantle at the mouth of the Swan River; and the capital, Perth, situated mid-way between the port and the foothills of the ranges.

The colony suffered in its early years due to severe food and labour shortages. Farming practices were not suited to the harsh environment; projected emigration had fallen short and there was no convict labour. Eventually, in 1850 the transportation of convicts was sanctioned, shepherding in a new era of economic growth. However it was not until the period 1890-97, following the discovery of successive gold deposits that the economy and population exploded. The resultant wealth and investment was poured into infrastructure projects: improving Fremantle harbour; and the construction of road and rail networks servicing mining and agricultural holdings (Appleyard, 1981).

In terms of the present study, the opening up of these agricultural areas and the construction of infrastructure in service of them is most pertinent. The once scrubby landscape of these holdings was subjected to broadscale clearing, and planted, mainly with wheat as well as other feed grains. Rail and road networks were extended into the areas, with nature reserves set aside alongside to preserve botanical species and wildlife.

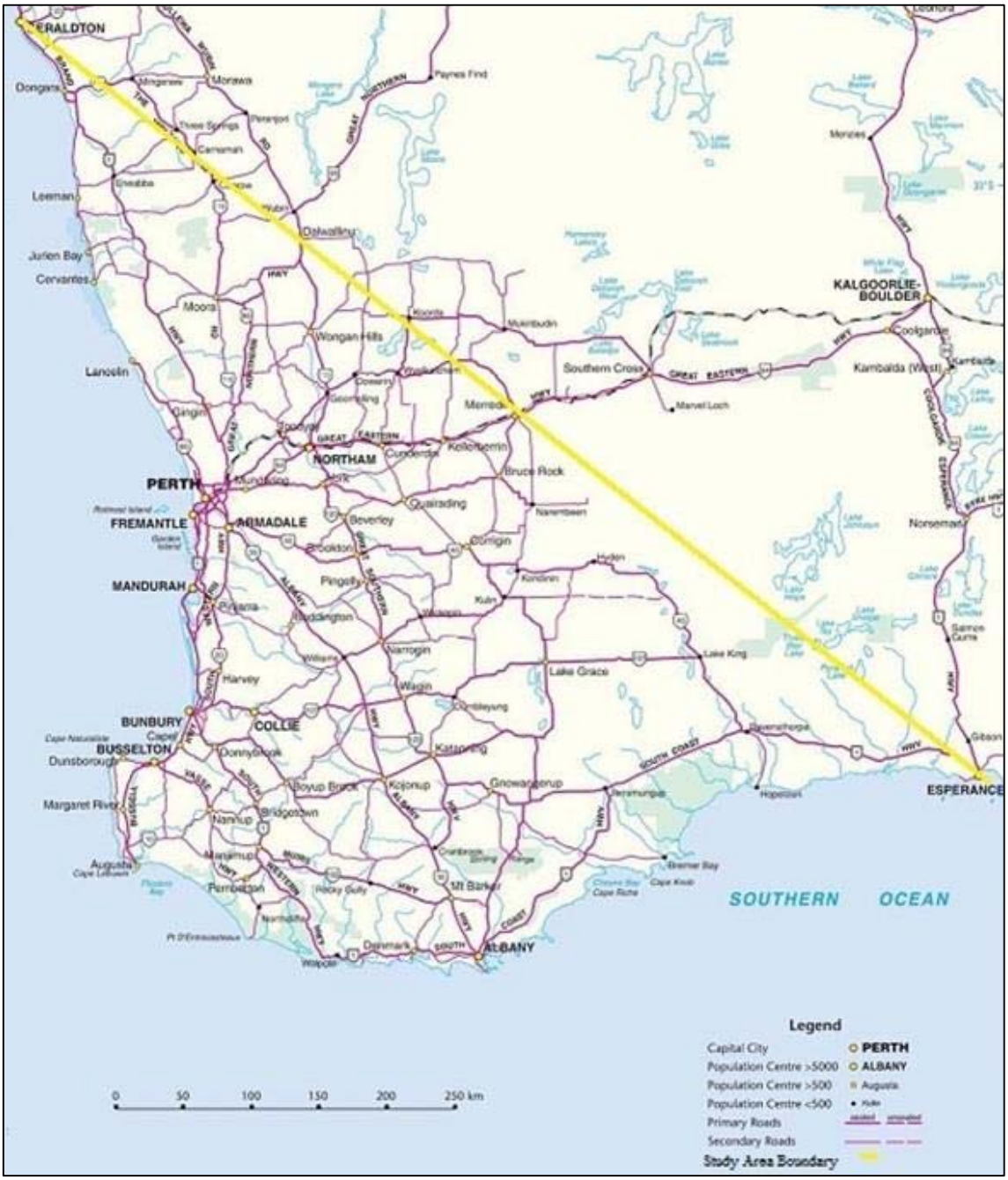
The transit pathways acted as vectors for the spread of wildlife into the highly modified landscape; a habitat devoid of physical barriers, that was easily accessible and offered an alternate food source. The dispersal of the Laughing Dove in particular shows a strong association to landuse and farming practices, and range expansion utilising transport routes.

More recently, economic growth linked to mining and resources has again accelerated population growth and placed demand on housing and infrastructure. As a result, the clearing of native habitat has continued to make way for urbanisation and infrastructure; adding to the challenges facing this unique and isolated environment.

The population of Greater Perth now exceeds 1.8 million people; or 78% of the State's population. Growth has been greatest in the outer suburban fringes in the north-western and south-western corridors. Regional WA also experienced increases, with the towns of Bunbury, Augusta, Margaret River and Busselton experiencing the second highest rate of growth (Australian Bueau of Statistics, 2011).

This brings to a close the descriptive narrative of the study area. As a point of reference for the remainder of the study, throughout which the movement of species into new localities is discussed, a map of the study area showing major towns has been included (Map 4.9).

The case studies will now be presented; commencing with the immigrant invader, Australian White Ibis.



Map 4.9: Map of Southwest showing Study Area boundaries and major towns
(Landgate, 2010)

5 URBAN USURPER: AUSTRALIAN WHITE IBIS: (*Threskiornis molucca*)

5.1 Nomenclature and Taxonomy:

The Australian White Ibis is known to the Yindjibarndi people of northern Western Australia, from where it originates, as 'Mardungurra' (Juluwarlu Aboriginal Corporation, 2005). This has a more distinguished ring to it than some of the vernacular names it has earned due to its habit of scavenging at refuse sites and from rubbish bins, that reflect these behaviours, including 'dump-chook', 'tip-turkey' and 'bin-chicken' (Thomas, 2007). There is also a tale to tell in relation to the official nomenclature pertaining to the species, which has long been a subject of contention and debate.

At times referred to as 'Sacred Ibis', its common name is listed as 'Australian Sacred Ibis' by global ornithological organisation BirdLife International (2008). Carrick (1962, p. 71), states the White Ibis shares a distribution and breeding range that takes in New Guinea and the Moluccas, "where it merges with the very similar sacred Ibis…of Asia, Africa and Europe". Similarly Lowe and Richards state the species complex includes forms ranging "from Africa, through southern and eastern Asia and into south-east Asia and Australasia" (Lowe & Richards, 1991, p.41).

Whilst Bekle (1982) in his study, recognises Australian White Ibis as a sub-species, his view differs to that of others who identified distinct morphological differences within the complex. Based on outcomes from their own research methods, in conjunction with a detailed review of prior research efforts (Amadon & Woolfenden, 1952; Benson, 1967; Benson & Penny, 1971; Gyldenstolpe, 1955; Mayr & Rand, 1937; Mees, 1982), Lowe and Richards (1991 p. 44), conclude the most current taxonomic classifications for the superspecies Sacred Ibis are:

- *Threskiornis aethiopicus aethiopicus;*
- *Threskiornis aethiopicus bernieri;*
- *Threskiornis melanocephalus;*
- *Threskiornis moluccus moluccus* [and]
- *Threskiornis moluccus pygmaeus*

Whilst the debate on nomenclature continues, this is not the forum for continued discussion. As for the purpose of this study, as with all the focus species, the nomenclature of Christidis and Boles (1994, 2008) is adopted. To clarify, any reference to 'White Ibis, or 'Ibis' pertains specifically to Australian White Ibis (*Threskiornis molucca).*

5.2 Physical Characteristics:

This distinctive species is easily recognised by its protruding curved, long black beak useful for digging in crevices and grasping prey, both on land and in water. It is quite large with males and females reaching 65-75cm in height; weighing 1.7-2.5kg (male); 1.4-1.9kg (female); with a wingspan 110-125cm; beak length up to (and over) 16.7cm (male); and up to 16.7cm (female) (Legoe & Ross, 2007).

Adult plumage is mainly white, often grubby looking; contrasted by a black head, black-tipped flight feathers and yellow tail feathers. The light plumage of the White Ibis is a distinguishing characteristic from other ibis species which are mainly darkly plumed. Females are smaller with shorter bills, as are juveniles, which are also less curved. They also retain black feathers on the head and neck and lack wing-plumes. The voice consists of "harsh barks, shouts" (Pizzey & Knight, 1997) (Plate 5.1).

Plate 5.1: White Ibis (*Threskiornis molucca*)
(Vengilat, 2012)
(Exception to copyright: Section ss 40, 103C for Research or Study)

When on the ground they may be appear ungainly, "rising heavily and noisily into flight" (Comrie-Smith, 1935). Once in flight, occasionally alone, but usually in a flock, sometimes with Straw-necked Ibis (*T. spinicollis*), they form and hold to a 'V' shape, moving in undulating lines in long glides powered by quick wing-beats.

In flight, they wheel high, with neck and legs extended in symmetry with the body. The symmetry of the body coupled with strong wing-beats powers long glides to optimise energy use for this highly dispersive species. The neck and legs are retracted for landing. Strong flight helps young Ibis "scatter widely from their natal colonies" (Carrick, 1962, p. 77), as has been evidenced in banding data (Plate 5.2Plate 5.3).

Plate 5.2: White Ibis in flight
(Tate, 2008b)
(Exception to copyright: Section ss 40, 103C for Research or Study)

Plate 5.3: Australian White Ibis, landing
(Tate, 2008c)
(Exception to copyright: Section ss 40, 103C for Research or Study)

5.3 Habitat and Food:

The ecological profile of the species is suitably flexible so as to not restrict it to areas of pristine habitat. This highly dispersive species is known to have travelled distances up to 15km from breeding colonies to feed (Blakers *et al.*, 1984). They have shown that during times of drought they will move coastward and if required, "seek food in unusual places" (Carrick, 1962, p.79). As a consequence it has become widespread throughout areas of human settlement.

This adept scavenger has learned to utilise food sources dug from lawns and pastures, orchards, public gardens and refuse sites. During the compilation of this project they have been observed scavenging in shopping centre car parks that experience high levels of vehicular traffic; and in rubbish bins at adventure parks that are noisy and bustling with people (Plate 5.4and Plate 5.5)

Plate 5.4: White Ibis in shopping centre car park at Maddington, WA
(Moon, 2008)

Plate 5.5: White Ibis at *Adventure World* theme park, Bibra Lake, WA
(Moon, 2010a)

However, it is the adaptability of this "essentially aquatic species to conditions of intermittent drought and flood" (Carrick, 1962, p.80) which makes it interesting to study. White Ibis feed in both fresh and brackish water making it suited to a variety of habitats. Like Sacred Ibis, White Ibis show a preference for the littoral zone closest to "the shallow margins of lakes and swamps, in fields near water and on coastal mudflats" (Blakers *et al.*, 1984) . They appear to make only "limited use of drier habitats" (Carrick, 1959, p. 69).

Their diet consists mostly of aquatic invertebrates including fish, reptiles, frogs, tadpoles and small crustaceans. Although they will also feed on small vertebrates such as small or young mammals, birds, eggs, as well as insects, spiders and molluscs (Pizzey & Knight, 1997). The extent to which they feed on insects is somewhat contested: A paper by Le Souëf describes their diet as consisting "mostly of grasshoppers, as well as fresh-water snails, beetles and caterpillars" (1917, p. 95) is contested by Carrick (1959) whose findings based on gut content analysis (of 200 ibises) found that aquatic species such as yabbies, frogs and fish were the most highly consumed food types. He also lists crickets, beetles, grasshoppers and locusts as taken in considerable number. To a lesser extent flies, moths, centipedes, cockroaches, spiders and cicadas, snakes, rats and mice were also consumed. Foods from 'dry' habitats were limited to ants and lizards. The findings of Carrick (1959) are concurrent with the latter findings of Barker and Vestjens (1989) (Table 5.1).

The study also examined the extent to which Straw-necked Ibis and White Ibis contributed toward the control of 'pests of economic significance' such as Australian plague locust (*Chortoicetes terminifera*); Small plague grasshopper (*Austroicetes cruciata*); Wingless grasshopper (*Phaulacridium vittatum*); Yellow-winged locust (*Gastrimargus nusicus*) and Spur-throated locust (*Austracris guttulosa*). Overall, Straw-necked Ibis consumed the greater amount at 61 insects (70.6%); whilst White Ibis consumed 26 (61.1%) (Carrick, 1959).

They are also appear to be opportunistic feeders, having been seen taking a snake at a wetland. Whilst feeding with other water birds the Ibis "captured the snake while probing round the banks of the island" (Morris, 1973, p. 73). Pursed by other Ibises and a pelican (*Pelecannus conspicillatus*), it did not consume the snake until well away from its pursuers. An article by Vestjens (1977) lists Mainland Tiger Snake (*Notechis scutatus*) as a food of White Ibis. The common link being that both utilise lignum bushes: Ibis for breeding, the Tiger Snake, for cover.

The species fondness for freshwater mussels provides insight into its ingenuity. Whilst feeding by birds on hard shelled objects such as snails, eggs and nuts has been documented (Chisholm, 1972; Hobbs, 1971; Rowley, 1968); Vestjens (1973, p. 73), gives an account of Ibis feeding on freshwater mussels, documenting the "first time that the use of an anvil and the use of a foot in holding food have been recorded in an Ibis".

Table 5.1: Main food types of White Ibis
Showing habitat types from which food is sourced
(Adapted from Carrick, 1959)

FOODS OF AUSTRALIAN WHITE IBIS Carrick (1959)			
Food Type, Classification	**Food Type, Common Name**	**Habitat Found**	**% of Total Sample**
Crustacea (Cherax albidus)	Yabbies	Aquatic	66.3
Gryllidae	Crickets (adults and large nymphs)	Average	32.7
Coleoptera (Carabidae)	Gound-beetles	Average	28.7
Amphibia	Frogs	Aquatic	19.8
Gasteropoda	Water-snails	Aquatic	18.3
Dytiscidae, Gyrinidae and Hydrophilidae	Water-beetles (adults)	Aquatic	17.3
Elateridae and Tenebrionidae	Click-beetles and tenebrio-beetles (adults)	Average	16.8
Acrididae	Grass-hoppers and locusts (adults)	Average/Wet	14.3
Actinopterygii	Bony-fish	Aquatic	12.4

The mussels were either swallowed singularly or several at a time and transported by flying or walking to an anvil site; regurgitated and opened; or swallowed without being regurgitated. Some Ibis lost mussels when they "shot away from between the toes of the foot holding it" (1973, p. 73). Although the anvil method proved fallible to some extent, it allowed sufficient feeding success at a time (mid-winter) when other foods were scarce.

The versatility of the species has served it well in developing feeding prowess in urban areas that encircles wetland areas they gather at, or in areas devoid of wetland habitat. The main problems associated with Ibis in these areas relate to them being generalist feeders that utilise a range of food sources. Adept scavengers, they are often present at picnic areas, alfresco cafes and refuse sites.

Whilst conducting research on Australian Raven (*Corvus coronoides*) they were observed obtaining food by retrieving scraps left on the ground or thrown by park visitors (often intended for ravens); eating scraps left by park visitors and scavenging at (overly full) rubbish bins. In each of these instances, the 'problem' behaviour of Ibis is linked to human behaviour: deliberate feeding by visitors (in violation of signage asking not to feed the birds); not disposing of waste properly or poor waste management at the site. These findings were confirmed by observations conducted for this project.

Another notable characteristic of their inter-specific interaction with Australian Raven was the spatial tolerance exhibited between them when feeding and bathing (≥1.0m). When on grassed areas, ravens would follow the ibis probing at holes in they made in the ground searching for food. Occasionally the ravens would fly-up and scatter, then land further away. This was often preceded by the larger Ibis moving toward or flapping their wings at the ravens, reinforcing ownership of space.

Like the Australian Raven, Australian White Ibis have become accustomed to living in close proximity to humans (Plate 5.6and Plate 5.7). Whilst this may bring increased feeding advantages, its urban existence may contribute toward declining breeding success. White Ibis are particularly sensitive to human interference and may abandon a nest if disturbed. The pair may not find conditions suitable to then breed again that season. As the species nest in a colony, this sometimes brings them into conflict with humans due to the noise and odour that can emanate from a rookery.

In preparation for breeding, the species display certain physiological features and ritualistic performances to attract a mate. However, once paired, breeding can be delayed until certain environmental conditions prevail. The next section discusses these factors.

Plate 5.6: White Ibis, near housing, Lake Joondalup, WA
(Tate, 2008d)

Plate 5.7: White Ibis next to house, Lake Joondalup, WA
(Tate, 2008a)

5.4 Breeding:

In White Ibis sexual maturity is not reached until three years of age. The average clutch size is 1-4 eggs; incubation is 21-23 days and fledging age is about 48 days. Juveniles are fed for around 14 days after they leave the nest. Subject to environmental conditions up to 1-3 clutches can be laid per season (Legoe & Ross, 2007). Although the higher number is not common even when conditions are optimal (Carrick, 1962).

Breeding plumage is prominent, the most distinct markings being a show of scarlet skin underwing. There is also a display of lacelike plumes over a yellowish white tail (Pizzey & Knight, 1997) (the species often nests with Straw-necked Ibis, which display corresponding yellow breeding marks underwing) (Plate 5.8).

This differentiation of breeding plumage is significant as the courtship display of both species involves wing flapping. The colour difference enables the species to coexist whilst remaining "reproductively isolated by behavioural mechanisms" (Carrick, 1962, p.74). Although both species will roost in trees, only White Ibis nests in them and only Straw-necked Ibis build ground nests.

Plate 5.8: Breeding display, scarlet markings underwing and yellowish tail
(Tate, 2008e)

In preparation for breeding, the male White Ibis first secures a pairing territory to attract a female mate, usually located on a branch of a tall tree. Courtship commences with a raucous display and shows of aggression toward other male Ibis nearby. The arrival of the female is met by the male bowing from the pairing branch and offering the female a twig. The pairing bond is formed when the female grasps it and they begin to preen each other. Once paired, the birds fly to another location to build their nest which is large, compact and shallow. The finished nest is an unruly construction of sticks and reeds. In natural environments nests are often seen suspended over water (>0.5m -1.0m.deep), in a stand of trees or trampled reed beds. An important function of nest placement is the protection it affords from predators, both ground-dwelling and avian attackers, particularly at sites where nests are concentrated.

The preferred vegetation types for nest construction are those strong enough to support it and keep it elevated, especially at sites surrounded by water. Often lignum, (*Muehlenbeckia* spp); (*Eleocharis* spp) and Cumbungi (*Typha* spp) is used. Each of these vegetation types is widespread throughout the study area. Other than these local species, introduced *Typha orientalis*, is also present at many wetland sites and is exploited by White Ibis for nesting. This incorporation of non-native vegetation types, as well as its utilisation of artificial nest structures in urban areas evidences its adaptability: a trait that has aided its colonisation success and contributed to its proliferation and widespread dispersal.

Nesting is not a solitary activity, but is conducted in colonies, often with other water birds and Straw-necked Ibis (Pringle, 1985) (Plate 5.9). A colony may number many hundreds as was the case at a rookery in Casterton, Victoria:

> Extending over an area of 6 acres, spread in an irregular fashion, is an immense matwork of trampled down rushes, forming platforms, some at the water's edge, others raised several feet and presenting the appearance of tiers. On these platforms, fighting, squawking, building, sitting, feeding young ones, leaving them and returning in an incessant stream and turmoil are thousands of the two species of Ibises (D'Ombrain, 1906, p. 187)

Habitually, first-comers to the nesting site settle in the centre which is why "you will frequently find young birds in the middle almost ready to fly, and fresh eggs at the outskirts, and all stages in order in between" (Le Souëf, 1917, p. 94).

Whilst the type and extent of fringing vegetation plays an integral role in nest site selection, other conditions also prevail. White Ibis respond to flood conditions, and possess an innate sense of the "essential proximate stimulus for breeding" (Carrick 1962, p.75). Breeding site selection is not in response to day length, rainfall, or food supply, but is determined by the instance of flooding of a suitable area.

Plate 5.9: White Ibis, in communal nest
(Lavender, 2007)

Observations by Carrick (1962) at Macquarie Marshes in New South Wales (NSW) 1954-1955 illustrate this. Throughout July- August 1954 the area attracted only few White Ibis and Straw-necked Ibis. Although the marsh remained dry, numbers increased slightly throughout September. An examination of male Ibis showed the testes were one-third developed, and in females the ovaries were not inhibited by non-breeding regression: indicating the readiness of the species "to respond to appropriate breeding stimuli" (Carrick, 1962, p.75).

Despite a super-abundance of food in early September due to hatching of Australian plague locust (*Chortoicetes terminifera*) and swarms of flying insects in October; gonad size did not alter, nor were there other evident signs of nesting. Whilst Straw-necked ibis vacated the site following poor September-October rains; White Ibis remained and deferred breeding until October-November when the area flooded (Carrick, 1962, p.75).

The findings of Carrick are similar to those evidenced in the present study: That breeding occurs mainly through September-December, but is not restricted to this period. Advantages of breeding at this time are that the eggs hatch and juveniles fledge in moist, mild, warm conditions. It also coincides with the hatching of various insect larvae, a ready food source for juvenile Ibis. Note the lack of breeding records for March-May, a time when the environment is at its most parched following low precipitation and high evaporation of surface water throughout Spring-Summer (Figure 5.1).

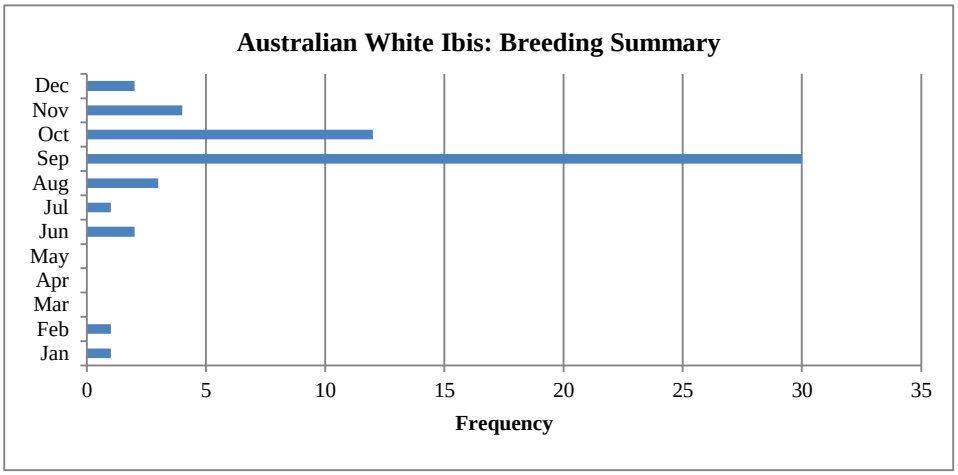


Figure 5.1: White Ibis: breeding summary
(Derived from the Present Study)

In his research Carrick also observed that laying may "continue for weeks and sometimes months after nesting starts" (1962, p.76) . This may be due to newcomers arriving to the colony or repeat clutches by Ibis following nest failure (from nests being flooded or abandoned). There is little evidence to support the notion that successful breeders lay again in the season as a brood fledges despite optimal breeding conditions. Although, this notion is subject to challenge as Ibis, in a natural setting, are difficult to observe and record due to the adults being wary and nomadic; also they nest colonially in harsh terrain; and abandon nests that are interfered with.

When adults feed the young each juvenile attracts the parents by calling and flapping the wing nearest to the adult possessing food. The extension of the wing captures the parent's neck to secure the head allowing regurgitation of food from a voluminous crop within the parent's throat. Despite appearing a chaotic enterprise, it is not an indiscriminate activity that pays favour to the most "importunate young" (Carrick, 1962, p. 76).

Rather, aid is determined by the young first establishing vocal recognition with the adult; the behaviour ensuring "continuance of the parent-nestling bond and the vocal basis of recognition" (Carrick, 1962, p.76). On the following pages, photographs show the stages of breeding: an adult tending egg in a communal nest; a newly hatched chick, a juvenile; and an adult feeding a juvenile (Plate 5.10; Plate 5.12 and Plate 5.13).

After leaving the nest, juveniles disperse widely from their natal colonies, and maintain this throughout subsequent years. The wide dispersal of the species is not restricted to juveniles, with recovered banded Ibis recorded as travelling more than 28km from the original banding site to feed at parks and landfill sites and throughout residential urban areas. (Legoe & Ross, 2007). The relocation of Ibis from traditional wetland sites into the city and surrounding urban areas has resulted in them being identified as a 'pest' species. Following is an overview of some of the problems that have developed subsequent to changes in the historical distribution of the species into new territories and habitats.

Plate 5.10: White Ibis, tending a clutch in a communal nest
(Butterworth, 2010)

Plate 5.11: White Ibis, hatchling and eggs
(Ward, 2010)

Plate 5.12: White Ibis, juvenile
(Ward, 2011)

Plate 5.13: Adult White Ibis feeding a juvenile Ibis
(Dunis, 2010)

5.5 Status of the Species in other Australian States and Territories:

Across Australia, the Australian White Ibis has been highly successful in adapting to the urban landscape. As a consequence, Ibis populations have grown exponentially in urban areas. Living in close proximity to humans sometimes results in problems, mostly due to a result of lack of familiarity of the two species with each other: at times when Ibis and people encounter each other in public space, people are wary of its large size and sickle-like beak.

Another obstacle to good relations is the propensity of the species to scavenge: from rubbish bins, as well as around picnic sites and al fresco cafes, sometimes on tables, which other than being bothersome, poses possible health risks. In locations where communal roosts are established close to housing, the odour of droppings and the incessant noise that emanates make Australian White Ibis poor neighbours.

Other than the odour associated with excessive defecation, droppings from communal roosts can alter soil composition and prevent some plant species from growing. This is especially problematic if the roost lies within a conservation reserve or botanical garden. Another problem arising from the establishment of Ibis colonies is the destruction of habitat that might have been utilised by other species. Discussion on these and other problems associated with urban populations of White Ibis follows, commencing with Victoria, which hosts large, long-term populations.

The story of Ibis in Victoria commences in the 1960s when several birds were captured in the north of the state and relocated south where they were kept in an aviary. After breeding successfully a few of the captive bred Ibis were released to lure wild Ibis to breed with them. As they were 'native' birds, this seemed a reasonable action unlikely to result in problems. However, within 20 years Victoria hosted a population in excess of 1600 Ibis; begging, scavenging, spreading rubbish and worrying at people with their sickle-like beak (David, 2008).

The species is well represented along the Murray River Valley and at times of suitably high rainfall, breeding occurs. In these and other regional areas in Victoria Ibis have learned to co-exist with humans. This is especially so in areas utilised for food production where the landscape has been vastly modified. As traditional roost sites and nest sites have become degraded due to over-drainage and drought, the species has moved into these alternative, modified habitats in search of food and water.

When Ibis relocate into areas of human settlement it presents challenges for people that are apprehensive due to their size, weapon-like beak and bold attitude. Nor is the species portrayed well with warnings issued by Government agencies about the propensity of Ibis to scavenge and steal food and nest in inappropriate places (Temby, 2003). However conversely, the species is praised as "a great benefit to landholders" (2003, p.1) when they occupy traditional sites such as tidal flats and grasslands, most probably due to their consumption of insect pests.

Although regional populations of Ibis are reasonably high, in the metropolitan area and around the city Ibis are not yet present in large numbers and do not behave in such ways as to be deemed a pest. A query directed to Melbourne City Council elicited the following response:

> Our Park Ranger co-ordinator has advised that on the odd occasion they have caused problems on very wet sports fields digging up the grubs and insects underneath and thus damaging the playing surface. But other than that, they normally hang out around ponds and wetlands (Personal Communication, Melbourne City Council Representative, 26 October 2009)

In Victoria, the species is protected under the *Wildlife Act* 1975 making any controls or management approaches subject to stringent regulations. However, there are issues of conservation to consider equally to issues of controls. Research by the University of New South Wales found substantial differences in contaminant levels in White Ibis eggs collected from urban sites, to those taken from inland rural sites.

The research project tested over 200 White Ibis eggs from urban and remote inland sites. In Victoria the sites were the Mud Islands, near Phillip Island and inland at Shepparton. Eggs from the urban sites displayed elevated chemical contaminant levels. Egg traits also differed between urban and rural populations, with eggs from urban colonies smaller in size, weight and volume than those from semi-urban and rural inland sites. Smaller egg size is related to reduced chick survival which may translate into urban Ibis colonies having reduced breeding success (Ridoutt & Kingsford, 2011).

Whilst contaminant levels in Australian White Ibis eggs are relatively low compared to Ibis eggs in other industrial countries, the research shows an established link between contamination and the proximity of breeding sites to urban areas. This is cause for alarm for both human populations and wildlife populations in urban areas, as Australian White Ibis are environmental indicator species (Edge, 2008; Ridoutt & Kingsford, 2011).

The elevated chemical contamination, which is seven to nine times higher in eggs from urban sites than rural sites, is most probably due to diet. In natural habitats White Ibis eat mainly aquatic and terrestrial invertebrates (freshwater crayfish, frogs, bony fish, worms and crickets) (Carrick, 1959). Whereas in an urban environment they forage in picnic areas, parks, zoos and landfill sites (Martin, French, & Major, 2010); and as observed during the present study, in car parks, domestic gardens and rubbish bins. As a result they ingest paper, plastics and electrical equipment (Rumbold & Mihalik, 2002), all containing toxic chemical compounds.

Similarly, eggs from urban sites in New South Wales, including the greater Sydney area and Newcastle, displayed elevated contaminant levels than those tested from semi-urban and rural sites. The Sydney samples contained compounds used in the manufacture of adhesives, paint and fire retardants. Whereas samples taken from the inland site at Macquarie Marshes, had elevated levels of compounds used in the manufacture of pesticide and fungicide by-products (Ridoutt & Kingsford, 2011, p. 4).

The species, which in New South Wales are protected under the *National Parks and Wildlife Act* 1974 , has experienced exponential population growth in the greater Sydney area over preceding decades. The population is thought to exceed 8000, whereas, prior to the 1950s, Ibis were rarely seen in these areas (Martin *et al.*, 2010). The growth is attributed to the movement of Ibis from inland sites due to prolonged drought; modification and damming of waterways and extraction of water for agriculture from wetlands historically utilised by the species for roosting and nesting.

The raft of problems arising from the influx culminated in a National Ibis Conference, held in Sydney in 2008. Here it was resolved that the NSW Parks and Wildlife Service were to develop a 'Sydney Regional Management Plan' to guide Councils and other stakeholders (Bankstown City Council, 2012). Urban Ibis have settled in parks, ponds and in some instances, palm trees. For, when present is large numbers, their behaviour, as well as the noise and smell that emanates from the colony causes distress to their human neighbours, with problems detailed in lengthy reports (Bankstown City Council, 2004a; Legoe & Ross, 2007) .

Co-author of the latter report, Dr Geoff Ross, also attributes the influx of Ibis into coastal urban areas to prolonged periods of low rainfall at traditional nesting sites. Where once populations were limited to inland sites such as the Macquarie Marshes many have headed coastward in search of food, water and habitat for roosting and breeding.

This has resulted in a conundrum for the species, with increasing coastal urban populations being offset by declining populations at inland sites. Reduced urban breeding success may be due to disturbance, or as detailed previously, poor egg quality. It is a situation, he says, that demands careful evaluation to ensure management upholds conservation values against calls for controls (Legoe & Ross, 2007).

Controls have already been adopted at some urban sites, such as Centennial Park east of Sydney. Ibis had settled at several freshwater ponds within the park and upon request, parkland management was granted permission by the NSW Parks and Wildlife Service to destroy eggs and nests. The practice occurred over several years, and as a result the Ibis relocated to other sites outside of the park (Cheshire, 2009).

The locality of Bankstown has also faced major problems with Ibis with local populations increasing markedly over successive years. At Lake Gillawarna, the number of Ibis present at the site has grown from 20 breeding pairs in 1999-2000 to more than 3000 birds by the 2003-2004 breeding season. A further survey in October 2004 estimated a population in excess of 1000 birds, including fledglings. The lake supports the largest Ibis breeding colony in greater Sydney; constituting 50% of the total Ibis population in the state(Bankstown City Council, 2004b). . Problems related to the incursion have even been reported in Parliament with the Member for Bankstown lamenting:

> …my electorate of Bankstown and surrounding regions are being terrorised, not by gangs of marauding youths resulting in increased crime…but by a terrible white bird weighing a maximum of 2.5 kilograms with an ugly long beak called the Australian White Ibis or to the scientists amongst us *Threskiornis molucca*... (Stewart, 2007, p. 3866).

The besieged community perceives Ibis as having little regard for people, wildlife or other birds; as scavengers well suited to urban life as they are capable of eating anything their long beak can pluck from bins and unsuspecting people. A population explosion in 2003-2004, saw them become so reviled at Lake Gillawarna, that locals and visitors stopped using the site. This was in part due to the smell of the colony; and because the species constantly scavenged for food, pursued children for food, and even snatched food from the hand (Stewart, 2007).

Local authorities were asked to develop a management plan addressing the "smell, noise and the possibility of disease, particularly *salmonella*" (Bankstown Torch Newspaper, 2004) linked to the colony; as well as address the issues of excessive excrement in trees and environmental damage to the site caused by the Ibis.

Following extensive community consultation, Bankstown City Council finalised a management plan (which became effective as at June 2012). It sets out stringent conditions in relation to active management strategies depending on the size of the colony. It proposes several population control mechanisms based on ecological manipulation to reduce numbers, such as vegetation management, roost dispersal, egg and nest removal and egg oiling.

Another strategy proposed is the use of electrified barriers to contain populations. Whilst presented as viable control options, the removal of nests and eggs, and the destruction of eggs to prohibit hatching and the use of electrification to contain the species are extreme and should only be put in to practice when all other options have been exhausted.

Whilst problems of behaviour, noise, smell and disease must be addressed, the impact of Ibis on the environment *per se* must also be considered. For example, at Fairfield near Sydney, White Ibis have been identified as the cause of a loss of habitat in an area used by a threatened population of Grey-headed Flying Fox (*Pteropus poliocephalus*) (Birds in Backyards, 2007). The advance of Ibis into territories historically used by other native species, especially those with specialised ecological requirements, demands attention.

Another site close to Sydney city, Taronga Zoo, has also faced problems related to White Ibis. A captive breeding colony was established there and the individuals later freed to roam the grounds. Once able to escape this urban enclave, it soon became apparent that the urban habitat well-suited the Ibis and they spread widely across the greater Sydney area.

Now problems with the Ibis scavenging at cafés, both on the ground and on table-tops, and spreading rubbish from municipal bins are widespread. They are renowned food-stealers, that will snatch food from the hand, especially from children who had to be taught not to fear them (David, 2008).

Another problem for the zoo, as in other purpose built conservation parks, the White Ibis filch food put out for other resident animals. Excessive defecation is also problem at these destinations as being large birds, they produce large droppings (David, 2008). Whilst these behaviours are problematic, another more serious threat posed by Ibis is that of aircraft strike.

Populations of White Ibis that feed or roost close to airports pose a high risk threat of aircraft strike. The species is particularly hazardous to aircraft due their size and body weight. A transport safety audit for the period 1991-2001, listed 'ibis' (species not specified) second only to eagles, as the greatest bird strike threat to aircraft safety in Australia: The audit reported 39 incidents of aircraft strike involving ibis; of which 41% resulted in damage to aircraft (Australian Transport Safety Bureau, 2002).

In Queensland, which also hosts large White Ibis populations, airports that service coastal centres, including Brisbane and Cairns (in the far north), recorded the highest number of bird strikes in Australia for the period 1996-1998. Of the 86 incidents recorded, nine involved ibis (species not specified) (Australian Transport Safety Bureau, 2002). Further south, at the Gold Coast, an airstrike incident involving White Ibis and a commercial airliner (Christmas Eve 1995) galvanised stakeholders into action. Airport staff was trained in how to disturb roosts and remove nests and eggs; the surrounding airport habitat was modified; drains were sealed and vegetation removed (Australian Transport Safety Bureau, 2005).

Another similarity between White Ibis populations in Queensland to those in New South Wales and Victoria arises from results of the research of Ridoutt and Kingsford (2011). Contaminant levels in eggs of urban Ibis populations in Queensland were again much higher than the levels found in eggs tested from remote inland rural areas.

Similarly, Brisbane and other coastal urban centres, such as the Gold Coast, and Bundaberg, have experienced similar social problems to those reported in other states: Ibis scavenging at parks and cafés, picking refuse from bins; defecating on property; being noisy, smelly and a nuisance at landfill sites (Paget, 2012). (Plate 5.14).

Plate 5.14: White Ibis foraging at landfill site
(Levy, 2009)

When numbers of White Ibis amassing at two of the main meeting enclaves in Brisbane city, Brisbane City Council adopted the unusual approach of hiring a bird handler to frighten them away with a wedge-tailed eagle (Roberts, 2007). The strategy was later adopted by the Gold Coast City Council as that locality was also being besieged by Ibis.

As, complained one Gold Coast Councilor, "you can't go to the park and get a chip from your lap to your mouth without it being gone" (Paget, 2012). Whereas, it is explained, when the eagle is present, the Ibis are unsettled and will not land. This limits feeding opportunities and they disperse in search of food. The plan has been so successful that the Council intends to use the eagle to clear other parkland sites in the district (Paget, 2012). This concludes discussion on populations of Australian White Ibis in eastern Australia. An overview of problems linked to the Australian White Ibis in the study area will now be presented.

5.6 Status of the Species in Southwestern Australia:

Australian White Ibis were once restricted to the Kimberley region in the north of the state. It is thought that drought conditions there forced the Ibis southward in search of food, water and suitable breeding habitat. Initial sightings of the first arrivals are dated 1952 (Bekle, 1982) in the coastal localities of Bunbury and Busselton, as well as inland at Coolup. Although the latter is not a coastal location, it is situated within the Ramsar listed Peel-Yalgorup wetlands system, which takes in Lake McLarty, a refuge for waterbirds and terrestrial fauna and avifauna.

Since the initial incursion the Southwest population has grown exponentially, especially in urban coastal localities. As a result, a raft of social and environmental problems, similar to those related to their eastern counterparts has surfaced. Most complaints relate to the noise and smell of roosts within urban areas; excessive defecation over vegetation and property and concerns about environmental damage at roosts and rookeries. However, the most common complaint about the species relates to it scavenging at parks and picnic spots, as well as landfill sites (Plate 5.15).

Plate 5.15: White Ibis, scavenging at al fresco café
(Unidentified location) (Schatz, 2010)

At the Perth Zoological Gardens, a personal experience with White Ibis caused some distress. Whilst dining with young children at the café in 2006, an adult Ibis flew onto our table to scavenge food. The children were scared by the large size and boldness of the bird, as well as its powerful, beating wings. A mêlée ensued as the contents of the table crashed to the ground as the Ibis scrabbled for purchase to land. Once landed, it deftly plucked food from the hand of the youngest child and then commenced to flail and flap its wings in her face as it made its escape.

Whilst calming the children, a check of the nearby area identified a number of other Ibis as well as several ravens and doves scavenging around the alfresco dining area. However, only the Ibis were on the table-tops as well as at the foot of tables. In making a hasty retreat, the matter went unreported. However, during subsequent zoo visits, it was noted the number of Ibis scavenging around the café was declining each visit which raised the question as to why?

In September 2008, an email directed to the Director of Animal Health and Research enquired as to the nature of complaints about Ibis within the zoo complex. Her response confirmed that White Ibis had been a problem at the site for some time, especially around the café area. Several strategies had been tried to manage resident Ibis but "their boldness in stealing food from the tables of cafe patrons" could not be curtailed. As some patrons fed them, this encouraged the activity. There were concerns that an Ibis might injure a child whilst stealing food and the health risks associated with Ibis walking on table surfaces. They also stole food put out for other species, so were not just a problem in the café precinct.

Initially scaring techniques (shouting, waving) were adopted when Ibis were caught raiding café tables; but as hand-feeding by patrons could not be curtailed, this "negated this as a control method". The next approach involved playing Ibis distress calls over the public address system. Initially the approach was successful, but after about a year, the Ibis had grown used to it. The calls were stopped for several months. Once they were recommenced they appeared to be effective again. Another proposed approach involved playing predator calls, such as Wedge-tailed Eagle (*Aquila audax*), in conjunction with Ibis distress calls. However it was deemed too risky as it may have disrupted the breeding program and distressed other animals (Personal Communication, H. Robertson, 07 September 2008).

Besides the nuisance value associated with White Ibis scavenging at cafés', picnic areas and meeting places, the practice has health implications. Other than the unsanitary practice of Ibis defecating on surfaces where food is served, they feed from rubbish bins and at refuse sites, allowing the transfer of disease pathogens (these are investigated later, refer page 119).

An enquiry as to whether White Ibis were present at municipal landfill sites; and whether when present, engaged in problem behaviour, was sent to all Local Government Authorities (LGAs) within the study area. Responses indicate that White Ibis are present at some metropolitan and regional landfill sites, in sizable numbers at some locations; and in some instances are deemed a nuisance as they spread rubbish and defecate over surfaces, including site machinery (Table 5.2).

Table 5.2: Status of White Ibis at refuse sites in the Study Area
(Source: The Present Study)

Status of Australian White Ibis at Refuse Sites in Southwest Region	
Local Government Authority	**Comments**
Armadale, City of	Number of White Ibis, ravens and pelicans feeding on landfill waste. Crows considered more of a problem as they remove waste from site.
Augusta-Margaret River, Shire of	Occasional visitor, low numbers. Scared away by heavy machinery operating on site. Waste covered daily to discourage scavenging.
Busselton, Shire of	Not present in large enough numbers to warrant control program.
Capel, Shire of	Two seen on site in apparent competition with ravens although not seen on site prior to 2009. Not considered a pest at this time.
Cockburn, City of	Significant numbers at Henderson Waste Recovery Park. Controls undertaken with culling permit granted for ravens and seagulls. However, Ibis and Pelicans also present in growing numbers. Problem obtaining cull permit due to conservation status of these species with Department of Environment and Conservation.
Collie, Shire of	Present in low numbers. Seen 'everyday'. About six each day.
Eastern Metropolitan Regional Council: Red Hill Waste Management Facility	Intermittent. Only present over last two-three years. Present in much lower numbers over winter/spring. Numbers increase steadily in Summer. Present in populations large enough to be considered a 'pest'. Working group set-up to investigate control options.
Harvey, Shire of	Recently sighted. Not seen prior to 2009. Presence noted by Environmental Health Officer as sightings considered 'unusual'.
Manjimup, Shire of	Numbers increasing (over last two years). As native birds may not be subjected to cull. Coverage of waste daily seen as satisfactory strategy to manage them as not yet present in 'problem populations'.
Waroona, Shire of	Intermittent. Management solution is to cover waste material to restrict access.
Rockingham, City of	Ibis and other native species (including ravens, kookaburras and various 'smallish' birds) are prolific at landfill sites managed by the City. In fact prolific at all refuse sites from east at Gidgegannup to the coast. Miller Road site, Baldivis has large population and it is increasing every week. Difficult to obtain cull permit due to conservation status of species with DEC.
Stirling, City of	Balcatta Transfer Station: Always have a 'fair few', probably about 100+ constantly throughout year, seem settled in habits at site. Cause mess fossicking in rubbish. Also OH&S concerns as they 'filthy' and defecate over surfaces, and even site personnel. Problems getting cull permit due to conservation status of species with DEC.

Although not yet officially classified as a ‘pest’ by authorities, some sites cover rubbish to prohibit access by Ibis (and other avian scavengers). It appears that Ibis numbers are increasing each year, which is raising concern with site managers due to the difficulty of obtaining control (culling) permits due to the conservation status of the species in the State

In WA the species are protected under the *Wildlife Conservation Act* 1950 and can only be removed under licence from the Department of Environment and Conservation. Generally permission to remove birds is only allowed subsequent to all other methods being trialled within a co-ordinated management program.

Managers at some sites expressed keen interest in finding out more about the scaring strategy put into practice by the zoo: that of playing Ibis distress calls, or alternatively, adopting the approach rejected by the zoo of playing the calls of a known predator, such as Wedge-tail Eagle, to disperse them.

Whilst the presence of Australian White Ibis within the study is not yet recorded in such numbers as their eastern counterparts, there is no doubt that urban populations are steadily increasing. This adept scavenger has adopted its generalist ecological profile to the vagaries of living in concert with humans, which, if left unchecked has the potential of generating sustained exponential population growth. In time, this may result in similar social and environmental problems that have arisen in other states when they large numbers of them are concentrated in urban areas.

5.7 Status of the Species Outside of Australia:

Australian White Ibis are closely related to Sacred Ibis (*T. aethiopicus*) and Black Headed Ibis (*T. melanocephalus*) which originates from the Indian continent. The former, is widespread throughout sub-Saharan Africa, where it is classified as being common, to very common within this African range. Populations are estimated at between 200,000-450,000 individuals (Delany & Scott, 2002). It was also once common in Egypt until the 19th century when populations died off inexplicably (del Hoyo, Elliott, & Sargatal, 1992). East of Egypt, in southern Iraq, a small, declining population has also been recorded in marshes (Delany & Scott, 2002). Introductions of Sacred Ibis have also occurred in United Arab Emirates and Kuwait.

In Europe, no fossilised remains have ever been found to suggest the species ever occurred there in the wild (Maurer-Chauviré, 1993). Although occasionally sighted in Italy in the early 19th century (Andreotti *et al.*, 2001), it is only since the 1970s that the species has established wild populations, bred of captive Sacred Ibis escaped from zoological gardens. Breeding pairs are now established in Spain, Italy and France and the Canary Islands (Yésou & Clergeau, 2006). Initially the incursions were welcomed, the tame birds added richness to the European avifauna, and the species had been celebrated since the time of the Pharaohs. However, it has since proven a serious predator of other birds, and is now much maligned.

Whilst populations have remained limited to specific locations in Spain, Italy and the Canary Islands, in France, Sacred Ibis have established sizeable populations which have bred from just 20 pairs imported from Kenya between 1975-1980, and ten more imported for another French zoo in 1987. A free-flying breeding colony was also established in a zoo in southern Brittany (Yésou & Clergeau, 2006). They have since established throughout western France, dispersing hundreds of kilometres along the French Atlantic coast (Frémont, 1995; Yésou, 2005). Most colonies have been established in marshes, but the largest colony ever discovered (in 2004), was on an artificial island within the Loire Estuary. By 2005 it housed over 800 pairs, bringing the French Atlantic breeding population to more than 1100 pairs.

The species has since crossed into northern Brittany, Normandy and eastern France, close to the Belgian border. Nearby, neighbouring Belgium and Germany also host several free flying colonies (Yésou & Clergeau, 2006). Whilst most utilise swamps and marshes; others use rubbish dumps to forage.

In Europe, Sacred Ibis are classified as opportunistic feeders which feed mainly on invertebrates but also take larger prey, such as fish, amphibians, eggs and young birds. Predation by the species has been observed in western France, against Sandwich Tern (*Sterna sandvicensis*), "with the ibises flushing the terms off their nests and then taking their eggs" (Yésou & Clergeau, 2006, p. 525).

Other species they prey upon include Black Tern (*Childonias nigra*); Whiskered Tern (*C. hybrida*); Common Tern (*S. hirundo*); Mallard (*Anas platyrhynchos*); Black-winged Stilt (*Himantopus himantopus*); Lapwings (*Vanellus* spp); Cattle Egret (*Ardea ibis*) and Little Egret (*Egretta garzetta*). Often predation by Sacred Ibis leads to the prey species abandoning colonies (Kayser, Clément, & Gauthier-Clerc, 2005). In South Africa, predation has been recorded against cormorant species. Here the White Ibis co-exists with related species at several Ramsar listed sites (no incidences of predation were recorded during the present study) (Table 5.3).

Table 5.3: Birds predated by Sacred Ibis (& related species at Ramsar Sites, WA)
(Adapted from Yésou & Clergeau, 2006)

Wetland Species Predated by Sacred Ibis in France and South Africa		
France and South	**Related Species at Ramsar**	**Common Name**
Anas platyrhynchos		Mallard
	Anas rhynchotis	Australasian Shoveler
	Anas superciliosa	Pacific Black Duck
Ardea ibis		Cattle Egret
	Ardea alba	Great Egret
Childonias nigra		Black Tern
Chlidonias hybrida		Whiskered Tern
	Chlidonias hybrida	Whiskered Tern
Egretta garzetta		Little Egret
	Egretta alba	Great Egret
	Egretta novaehollandiae	White-faced Heron
Phalacrocorax spp		Cormorant spp
	Phalacrocorax melanoleucos	Little Pied Cormorant
	Phalacrocorax sulcirostris	Little Black Cormorant
	Phalacrocorax varius	Pied Cormorant
Sterna hirundo		Common Tern
Sterna sandvicensis		Sandwich Tern
	Sterna caspia	Caspian Tern
	Sterna nereis	Fairy Tern

Whilst none of the cases listed in France or South Africa has had a serious impact on existing populations, conservationists are concerned that predation by Sacred Ibis may increase as populations swell, and be directed toward vulnerable species.

Like White Ibis throughout Australia, and within the study area, Sacred Ibis of Europe have adapted to living in close proximity to human settlements. They appear to have become accustomed to disturbance in the form of industry and commerce and pedestrian and vehicular traffic; utilise alternate roosting habitats in ornamental parks and gardens; and have modified their diet to include manufactured food stuffs (Plate 5.16).

These qualities have allowed this adaptive and dispersive species to successfully transition from natural environments, into urban centres.

Plate 5.16: Sacred Ibis feeding from commercial bins, France
(Photographs: Yésou & Clergeau, 2006)

5.8 Health and Sanitation Issues:

Landfills have been identified as a source of salmonella for gulls and ravens and are likely a source of contamination for Ibis. That White Ibis feed at refuse sites and from rubbish bins and are able to disperse into areas populated by people, especially where food is consumed, poses a potential health risk. The threat is more real than imagined, with results of research by Epstein *et al.* (2006) examining White Ibis viral serology and bacterial culture, found that in Australia, the species hosts zoonotic and livestock pathogens such as *Salmonella* spp., Newcastle disease virus (NDV), avian influenza virus (AIV), and flaviviruses(Table 5.4).

Table 5.4: Summary of pathogens detected in White Ibis
(Adapted from Epstein *et al.*, 2006)

Summary of Various Pathogens Detected in Australian White Ibis		
Organism	**Disease**	**Potential hazard to:**
Avian influenza virus	Avian influenza	Poultry, humans
Candida	Fungal infection	Ibis
Coccidia	GI tract parasitism	Ibis
Flavivirus, generic	Various	Humans
Haemoproteus	Blood protozoan infection	Ibis
Helminths	Intestinal parasitism	Ibis
Hendra virus	Pneumonia	Humans, horses
Japanese encephalitis virus	Japanese encephalitis	Humans, pigs
Kunjin virus	Kunjin encephalitis	Humans
Murray Valley encephalitis virus	Murray Valley encephalitis	Humans
Newcastle disease virus	Newcastle disease	Poultry
Salmonella spp. *S. birkenhead* *S. oranienburg* *S. typhimurium* *S. virchow*	Salmonellosis	Humans and livestock
Vibrio cholerae		Humans

The same study also measured contact rates among Ibis, people and livestock to ascertain the potential for disease transmission found that the occurrence of AIV, *Salmonella,* and flaviviruses posed significant risks to public health. Further, diseases such as NDV, AIV and *Salmonella* presented a serious risk to livestock.

Other research outcomes identified that, dependent on location, White Ibis interact daily either with either domestic animals or humans, directly and indirectly. Whilst no documented reports of salmonellosis in humans are linked to White Ibis, three of the four salmonella types isolated from White Ibis (*S. typhimurium, S.virchow and S. birkenhead*) regularly afflict humans. It is also possible these pathogens may be exchanged between Ibis and poultry, which poses risks to the poultry industry (refer page 120).

Epstein *et al.* also recorded instances of White Ibis standing on picnic tables, bathing under, and drinking from public water taps (also used by children for drinking and washing their hands). Such occurrences hint at the prospect of transfer of zoonotic pathogens, like salmonellae or influenza A-virus through environmental contamination.

Water has been identified as a significant factor in interspecies transmission of influenza virus among water birds. In some instances freshwater samples have been shown to harbour the virus for up to 60 days (2010, p. 7).

The results from the behavioural study also noted a high correlation between the rate of people feeding Ibis and the rate of Ibis in close proximity (within 3.0m) to food when people were present, compared to when people were absent. This suggests that Ibis have become habituated to the presence of people and identify people as a food source; similarly, people accept the presence of Ibis when eating. Ibis also stood on food objects when people were absent, allowing contamination of food surfaces without people knowing. Public education regarding hygiene controls (hand-washing, wiping or covering surfaces where food is prepared or served) is advised.

The Ibis observed at a poultry farm had unrestricted access to hen-houses due to the open design of the structures. This enabled contact between Ibis and free-ranging hens, caged hens, eggs and with faecal matter collected under battery cages, thus providing a "potential route of pathogen transmission between poultry and ibis" (2010, p. 7). Due to the highly dispersive nature of Ibis, the potential risk of the spread of pathogens amongst farms is high. The installation of physical barriers to prohibit access by Ibis is recommended to significantly reduce the risk of NDV, AIV, or *Salmonella* exchanges between Ibis, other wild birds, livestock and poultry.

This concludes discussion on issues linked to sanitation and health in relation to the Australian White Ibis, and the potential risks of the transfer of pathogens harmful to humans and livestock.

The following discussion reiterates the approaches adopted in the data analyses used in investigating the colonisation and dispersal of the species throughout the study area.

5.9 Data Analysis:

The following summary of the analyses is not limited to Australian White Ibis, but applies to each of the case studies presented. The analyses are based on the presentation of spatial and temporal data prepared explicitly for the present study. The analyses for each of the focus species are depicted as a map series: Era A (1898 -1953); Era B (1954-1980); Era C (1981-2007) and All Eras (1898-2007); as well as *Spatial Statistics*; and in relation to climate and landuse data specific to the study area (refer Chapter 3, pages 45 & 55- 56).

Principally, as a geographic exposé, the study aims to investigate conditions related with the focus species arrival to, and dispersal throughout the study area; rather than conduct an exhaustive statistical analysis of each event. Essentially, the maps and their related discussion are intended to 'tell the story' of each species adaptation to the study area and identify possible impacts for local species and ecosystems.

In the data analysis the approaches and concepts discussed in the theoretical framework are applied. In the broadest sense, the discussion adopts the approach of C.S. Elton; examining the phases of invasion i.e. arrival, dispersal and impact; as well as conditions that kept invaders out of natural communities and prevented them surviving in adopted habitats.

The discussion also extends to consideration of the physical obstacles an invader must overcome to establish a population, i.e. temperature, moisture, vegetation (as per Groves & Burdon, 1986). Also, the habitat requirements of the invader are reviewed, 'where it lived', "as distinct from its 'ecological niche'. Also, (as per Williamson, 1996), the idea of a species being better suited to the climate conditions of the study area depending on its origins, are considered.

The adaptation of the species to the adopted landscape is set within 'ecological time', rather than 'evolutionary time'' (as consistent with the approach of Drake *et al.*, 1989). Whilst there is a chance that the invader has added to the species richness of the system, discussion reflects upon whether the presence of the focus species is as innocuous or beneficial to local ecosystems as it first appears (as per R.L. Kitching, 1986).

However the main conceptual framework upon which the present study is based is the *Invasion Process Model* of Lockwood *et al.* (2007) (refer Chapter 2, page 12). The adaptation of the model to the present study prescribed the classification of the data used in the GIS analysis.

The model commences with the mode of transport of the invader into the area, then demarcates the invasion process into three stages, each which is met with varying success. The three stages are: (i) *Introduction, Death or Captivity* (Era A)*;* (ii) *Establish or Fail* (Era B); and (iii) *Spread or Remain Local* (Era C).

The model also provides for consideration of the perceived impacts of the invader on its adopted habitat. The contention of the model that biological invasion events are a result of a process involving a complex interplay of biological, ecological, environmental and social factors provided the framework for the discussion.

The *Invasion Process Model* also considers the role of 'transport pathways' which led to the proposition that population retractions are less likely to occur along transport vectors that have experienced ecological disturbance. One of the most commonly cited truisms in the study of biological invasion is that 'disturbance facilitates invasions'. Just how-so, and how much, is fundamental to most investigations of biological invasion phenomena.

The present study was not formulated to make in-depth investigations of ecological theory, but rather to apply general ecological principles to contextualise the discussion. The concept of 'disturbance' is touched on; as is 'resistance' (loosely defined as any factor that repels non-natives; or more broadly, acts to reduce the probability of colonisation and spread). The concept of biotic resistance extends into discussion about 'competition'; a frontline defence against invasion i.e. resistance occurs when the arrival and establishment of a non-native species is impeded as the resources it requires are already in use by existing native species in that habitat. These factors in turn link to the defence of 'territory' in the pursuit and protection of resources. To this end, appraisals are made as to the functional 'Territory Type' maintained by each of the focus species (as per Hinde, 1956) (refer Chapter 2, page 31).

These ecological concepts tie in with principles of how human socio-political actions might have acted as a barrier or bridge to colonisation; promoting or inhibiting spread of an invading biological species. From these points several assumptions have been identified that relate to colonising species and the types of habitats they invade, which are reflected in the 'Invasibility Rules' set down by Brown (1989) (refer Chapter 2, page 18). Discussion will be drawn toward these points also.

Another issue related to the integration of non-native species into local ecosystems, says Lockwood, are the 'individual impacts', which might include "changes in morphology, behaviour or demographic rates of natives in response to introduced predators or competitors" (in Lockwood *et al.*, 2007, p. 186). Examples of 'behavioural shift' identified in the focus species in relation to feeding and breeding behaviours will also form part of the discussion.

The final aspect of the discussion pertains to the dispersion of the focus species: which put simply is "the internal distribution pattern of individuals within a population" (Emmel, 1973, p. 64). The dispersion of a population is linked to the availability or scarcity of resources with the established range. As a result, the distribution of a population may follow a generalised pattern. Within the present study, the patterns of dispersion identified, arising from the spatial autocorrelation analyses of the data using Moran's I and *Average Nearest Neighbour* statistics were: (i) random; (ii) clustered; or (iii) dispersed (refer Chapter 3, pages 58-59).

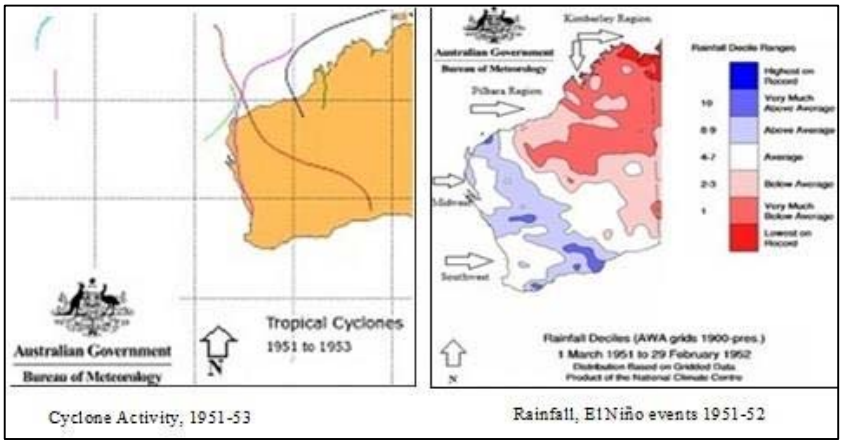
Although every effort was made to ensure the integrity of the data, upon which the following summaries are based ,were not compromised and are as true and correct as possible, a timely reminder that it is subject to limitations is proffered. The analyses that follow are based solely upon the sightings recorded and are cannot claim to be a definitive summary.

5.9.1 Transport:

The first aspect of the *Invasion Process Model* deals with the transport of the invader. Australian White Ibis is the only focus species that made its way to the study area without the aid of human conveyance. Prior to 1952 this immigrant to the Southwest was limited to the Kimberley in the far north of the state. Its distribution was mainly along the coast, although near the border with the Northern Territory, it spread inland. This is probably due to the availability of water and habitat fed from the river systems of the region, including Ord River Lake Argyle.

How or why the species made their way south is undetermined. There are two theories: The first is that tail-wind from a tropical cyclone propelled them southward; the second, that prolonged drought drove them south in search of alternative habitats.

Whilst Bureau of Meteorology data (Map 5.1) shows there were cyclones in the region in the period 1951-52, the course it takes pushes into the interior (red line), terminating in the Southeastern sector close to the border with South Australia. It is unlikely that winds from the event guided the initial coastal incursion of White Ibis into the Southwestern corner *circa* 1952. Another cyclone in the 1953-54 seasons (pink line) however plots parallel to the coast, directly into the Southwestern corner. Winds from the event could have assisted immigration southward; although not the first wave of immigrants Consecutive El Niño events for the periods 1951-52 had a strong impact across northern Australia, including Western Australia Below average, to lowest on record rainfall, was recorded across the Pilbara and Kimberley regions causing drought conditions. The same El Niño system bought average, to above average, rains to the Midwest and Southwest.

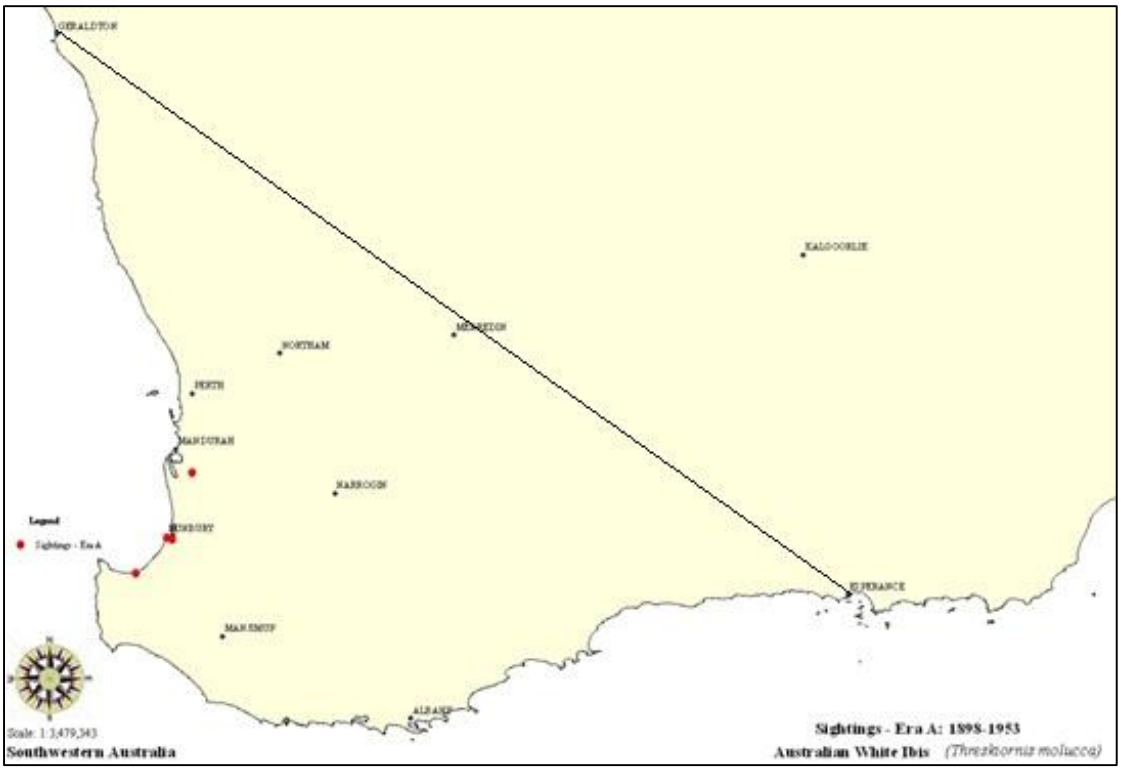


Map 5.1: Cyclone activity 1951-53; and El Niño climate events 1951-52
(Adapted from Bureau of Meteorology, 2012b) (Bureau of Meteorology, 2010)

So it seems more probable that the species headed south in search of alternative habitats rather than were conveyed by cyclonic wind gusts: but this statement is, at best, conjectural.

This concludes the examination of how the species arrived to the study area. Discussion now turns toward invasion processes, as per the stages of Lockwood *et al* (2007); commencing with Era A (1898-1953), 'Introduction, Death, or Captivity'.

5.9.2 Era A: 1898 – 1953: Introduction, Death or Captivity:



Map 5.2: Dispersal of White Ibis, Era A: 1898 – 1953
(No Breeding)

Following on from transport, discussion moves to Era A (•) 1898-1953, *Introduction, Death or Captivity* (Map 5.2). This is the first stage an invader must pass through before becoming established in the area it has colonised. The initial sightings of Australian White Ibis in the Southwest region were recorded in 1952. These were recorded simultaneously, in May, in the coastal locality of Bunbury, inland at Picton on the outer perimeter of Bunbury, and to the north of Bunbury, further inland at Coolup. By 1953 the species was also sighted in the coastal settlement of Busselton

Each of these localities supported human settlements: Bunbury, as a regional commercial and administrative centre for government services and private enterprise. These were mainly in support of primary industries such as forestry, sheep, wheat, fruit and dairy farming.

Dairy farming was prevalent in the region and extensive tracts of the surrounding landscape had been irrigated for this purpose to progress the 'Group Settlement Scheme', a government programme of supported immigration.

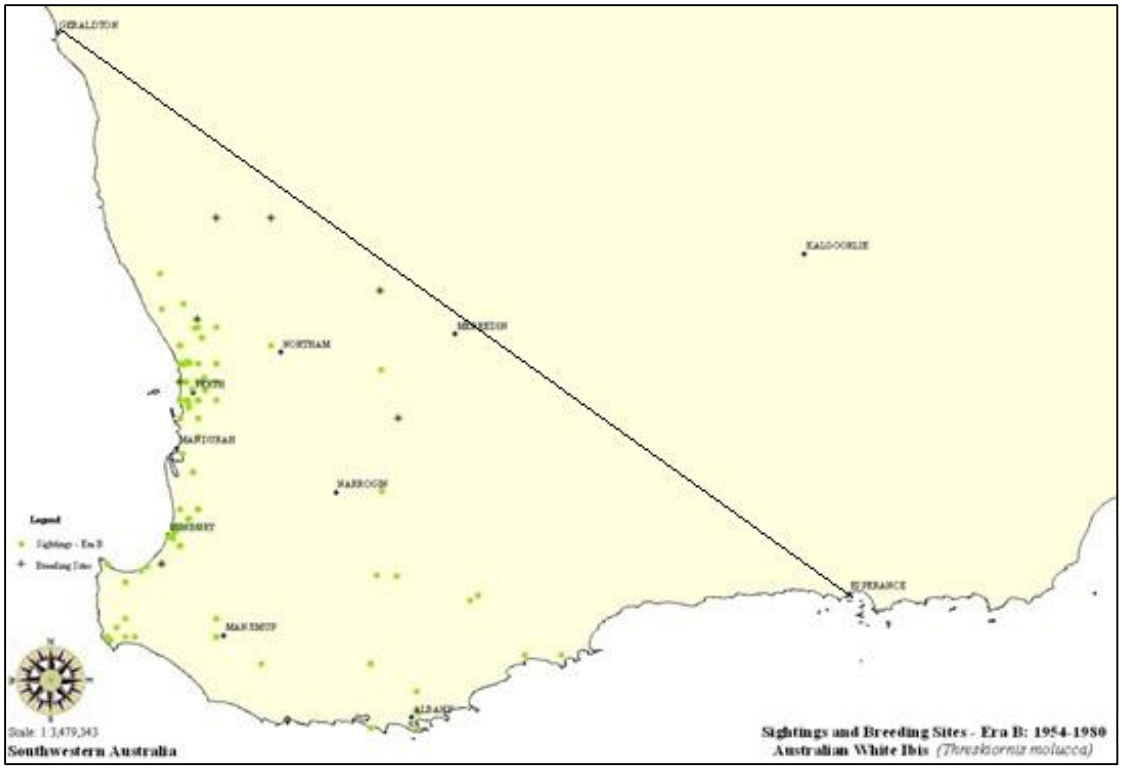
Irrigated pastures were fed from surface and groundwater sources, which also fed localised swamps and wetlands; habitat well suited to the White Ibis. The moist conditions supported an array of insect, beetles and worms, which were a ready food source for the Ibis. The swarms of flies and insects were probably swollen due to increased breeding in stockpiled cattle dung.

As the cattle raised in the area were also introduced breeds, and they produced dung of a different a type to indigenous animals (native dung beetle species had co-evolved with marsupials that produced, hard, fibrous nuggets of dung, not large moist pats). The number of cattle farmed, produced dung in such amounts, that native dung beetles could not process it quickly enough to prevent fouling of pastures and harbouring of insect eggs and larvae.

The pats were the perfect breeding ground for eggs and larvae for species including the introduced buffalo fly, native bush fly and biting midges (*Culicoides*) (CSIRO, 2003). For Ibis, the setting provided food sources by means of the native dung beetle, as well as the larvae harboured in, and flies attracted to the pats. This was ecologically advantageous to them as these types of insects form a core part of their diet.

In the course of research for the present study, no documented or anecdotal evidence was found to suggest these first arrivals either perished, or were captured. Its numbers continued to grow and spread out throughout the study area. These aspects will now be examined.

5.9.3 Era B: 1954 – 1980: Establish, or Fail:



Map 5.3: Dispersal of White Ibis, Era B: 1954 – 1980
(Includes Breeding)

By the next phase of the invasion process, Era B (•) 1954-1980, *Establish or Fail* (Map 5.3), it is clear from the depiction of the data that the Southwest population continued to expand. As sightings in the northern sector (latitude south 28.78 to 31.20) were not recorded until after the species was already established in the southern sector, all data are treated as belonging to the parent population of Era A (Table 5.5).

Whilst dispersal is predominant along the coast there are also inland sightings, some which push deep into the arid interior within the northern, central and southern Wheatbelt. Most breeding records are linked to inland sightings, which supports a similar scenario to other states, with the species moving to isolated inland habitats to breed, and moving toward the coast when food and water are scarce.

The only coastal breeding record, dated 1979, at Ludlow, between Bunbury and Busselton, is sourced from the first *Atlas* (Blakers *et al.*, 1984). It supports the assertion by the authors that breeding by White Ibis in the wild did not occur until this time.

However, records included in the Storr-Johnston databank include breeding events at some sites from 1956-1958: at Gingin (1956); Nembudding (wheatbelt, near Kellerberrin, 1957); and Pekaring Hill (wheatbelt, between Corrigin and Bruce Rock, 1958). These incidences were sometimes in the company of nesting Straw-necked Ibis.

Table 5.5: White Ibis Sightings –Latitude South 28.78 to 31.20
(Source: The Present Study)

Australian White Ibis Sightings (*Threskiornis molucca*) Latitude 28.78 to -31.20 (* Denotes: In the vicinity of)				
Year / Era	**Location**	**Breeding**	**Latitude South**	**Longitude East**
1998 Era C	Geraldton	0	28.78	114.61
2007 Era C	Greenough	0	28.92	114.7
1995 Era C	Irwin	0	29.22	115.08
1955 Era B	The Tuarts Reserve*	1	30.42	116.08
1999 Era C	Moora	0	30.64	116.01
1992 Era C	Doopiter Swamp	0	31.04	115.54
1999 Era C	Mogumber Reserve	0	31.06	116.04
1991 Era C	Karakin Lakes	0	31.07	115.48
1957 Era B	Cowardine Well*	1	31.08	117.58
1983 Era C	Brown Lake	0	31.1	118.28
1981 Era C	Wannamal, Lake	0	31.12	116.05
2002 Era C	Udumung Reserve	0	31.18	116.17
1977 Era C	Beermullah Lake	0	31.2	115.78

Other than this deviation from previous reports, the data support the proposition by Serventy and Whittell (1976) that White Ibis had extended inland to the south-central wheatbelt localities of Lake Toolibin, east of Narrogin by 1957; and Lake Ewlyamartup (near Dumbleyung), by 1958. These sightings however, relate to only one or two individuals, whilst records from 1962, indicate the species were present in some number (12) at Wattle Grove, a suburb in the outliers of Perth, in the foothills of the Darling Range.

As the tabled data relating to this phase are too numerous to express fully (485 records), sightings recorded within a decade of the commencement of Era B (1954-1962) have been extracted to show new sightings localities subsequent to the initial coastal incursion (Table 5.6).

It shows that within a decade the species had spread to isolated inland localities, and conversely, along coastal localities of intensely settled urban habitats. Other than at Wattle Grove, records indicate the species had spread into suburbs closer to the city, such as Coolbellup and Bibra Lake.

At the time, Bibra Lake, so-named for a semi-permanent wetland around which the suburb is built, was not intensely settled but was more a semi-rural enclave. An adventure theme park is now located immediately across from the lake. The facility attracts a large volume of visitors that bring food into, or purchase food stuffs at the site. The close proximity of the park to the wetland, a permanent White Ibis roost, has seen the species become a frequent and somewhat worrisome guest there.

Table 5.6: White Ibis, new localities listings: 1954 – 1962
(Source: The Present Study)

Australian White Ibis (*Threskiornis molucca*) (New Listings Only) (* Denotes: In the vicinity of)			
Year	**Month**	**Location**	**Breeding**
1954	Jun	Bunbury	0
1955	Apr/Jun	Leschenault Estuary	0
1956/57/58/60/61/62	Jan/Feb/Mar/Jul/Aug/Dec	Bibra Lake	0
1956	Sep	Gingin	1
1957/58	Mar/Aug	Preston River	0
1957	May	Picton	0
1957	Dec	Toolibin Lake	0
1957	-	Nembudding South Nature Reserve*	1
1958	Apr	Wellesley River	0
1958	Jan	Lake Ewlyamartup	0
1958	-	Pekaring Hill*	1
1960/62	Jan/Mar	Coolbellup	0
1961	-	Lower King	0
1962	Jan/Oct	Wattle Grove	0

Another anthropogenic factor that might have relevance to the colonisation and spread of White Ibis is the release of exotic dung-beetles into the Southwest. The beetles were bought in to curb insect larvae, flies and worms associated with pastures fouled by accumulated cattle dung.

The project, an initiative of CSIRO and Australian Meat Research Committee, imported 43 species from Hawaii, Europe and Africa between 1969-87, of which 23 species became established (CSIRO, 2012).

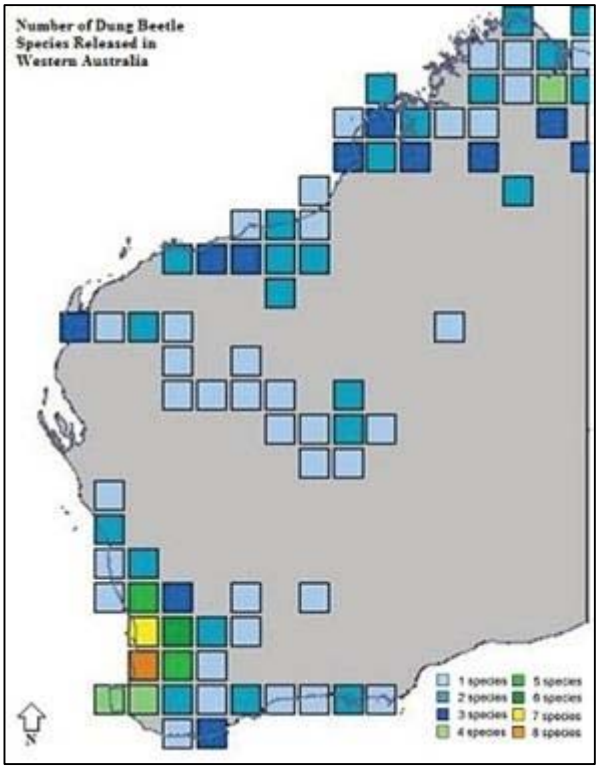
A Department of Environment and Conservation (DEC) fact sheet lists 'ibis' as feeding extensively on introduced dung beetles and their larvae in the Southwest (2009). The claim is supported by records in Barker and Vestjens (1989) that lists Scarabaeinae (*Onthophagus* spp) in stomach contents of Sacred Ibis (*T. aethiopicus*); the species name until recognised as a distinct species in Christidis and Boles (2008).

The beetles released here include species from this sub-family, including *O. gazelle* and *O. Sagittarius.* Other than White Ibis, *Egretta* spp also fed on them and all these types of birds were viewed as blight by dairy farmers, as they were seen to decimate dung beetle numbers (Map 5.4).

However, despite this potential food source throughout widespread pastures, populations appear concentrated along coastal settlements between Perth and Bunbury. The cluster of sightings in the western corner of the south-west peninsula is probably linked to the area that spills the Blackwood River, which may provide good foraging for insects, and besides, which, is a popular spot for tourists.

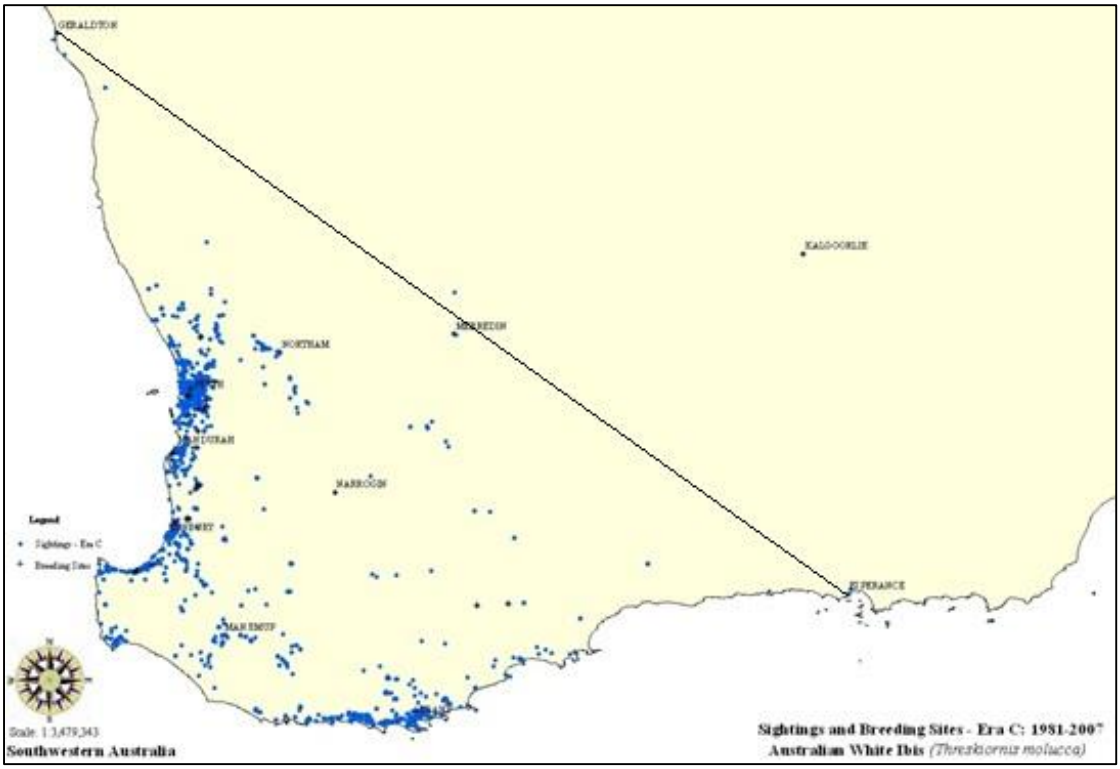
The depiction of Era B data shows that by this stage the species had adapted to living in proximity to humans. Its flexible ecological niche had allowed it to make use of alternate food sources to those found at traditional sites.

The second stage of the invasion process had been transcended, with breeding occurring in the wild at some sites. Populations were dispersed linearly along the coast and the interior, probably related to sites of natural drainage (lakes and wetlands) or farm dams. The discussion now moves to the final invasion phase, *Spread or Remain Local.*



Map 5.4: Extent of dung beetle releases throughout Western Australia
(Adapted from Edwards, 2007)

5.9.4 Era C: 1981 – 2007: Spread, or Remain Local:



Map 5.5: Dispersal of White Ibis, Era C: 1981 – 2007
(Includes Breeding)

The third stage of the model, Era C (•) 1981-2007, *Spread or Remain Local* (Map 5.5), examines whether, once established, colonised populations remain localised, or increase in their range. In the case of White Ibis it is apparent its distribution did not remain localised, with sightings extending to the study area boundaries and beyond.

The presence of the species in coastal urban areas has also increased substantially. There is also a notable increase of the species inland from Albany, around Mount Barker, which is a burgeoning cattle producing district, and was also the focus of dung beetle releases.

Whilst the release of these beetles may have been a contributing ecological factor to the success of the species in the second stage of the invasion process, especially during the latter stages of Era B, by Era C, the 'Dung Beetle Project', was being wound down, with releases limited to the redistribution of existing beetle populations.

The ecological advantage afforded White Ibis as a consequence of the initiative had possibly begun to diminish part way into this phase. Although the project was later rejuvenated with more beetle releases, the releases do not fit the limits of the present study.

As a result of this food source diminishing, the species probably had to expend more energy to obtain food from other sources, such as wetlands, or pastures. This contextualises the increased intensity of sightings records within coastal urban areas. As, in urban areas, foraging success is aided by access to tracts of lawn and cultivated gardens to pick-over (Plate 5.17). These pickings can be further substituted with food refuse. In ecological terms, in urban areas, less energy can be expended, for greater energy returns.

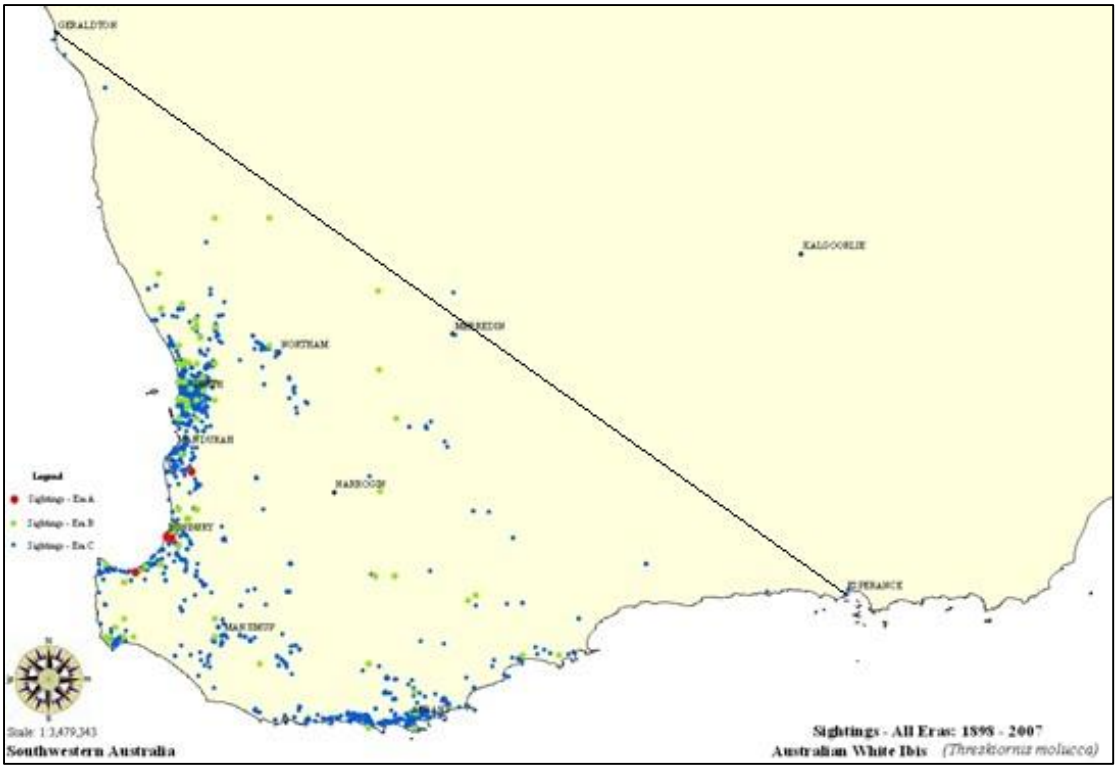
Here in Perth, the species has invaded refuse sites and public areas, as well as parks, picnic grounds and popular tourist venues. This includes sites such as the zoological gardens, and amusement parks, such as the one situated immediately opposite the wetland area of Bibra Lake. At this site in particular, White Ibis are used to rummaging in bags, as well as under towels and blankets to locate food. They scavenge at the café areas and at bins, as well as alight on café tables. Sometimes children are relieved of their food. Any complaints made to staff elicit a resigned response, and a request for customers not to leave food uncovered or unattended, and to keep watch against the marauders.

Around Busselton, around the site of sightings associated with the first incursion of the species into the study area, in 1953, it has become so abundant that an entire residential sub-division has been named in reference to them, *Ibis Gardens*. Advertising material features a picture of the species(*The West Australian Newspaper*, 2008), and promotes the proximity of the estate to a conservation area, which hosts a major Ibis roost.

In the advertisement, people are lured by the promise of the "sights and sounds of abundant birdlife attracted by the precious waterway… the *Ibis Gardens*. Relaxed, peaceful and pleasant" (Satterley, 2008, 2012). This may be arguable given that the species is highly vocal, and roosts and nests colonially. During breeding, they also establish a vocal parent-juvenile bond. Also, as large birds, they produce large droppings. The approach to utilise the species in marketing the appeal of the estate has altered the perceived profile of the species from being a liability, to an asset!

Plate 5.17: White Ibis foraging in suburban garden, Myaree, WA
(Moon, 2010b)

5.9.5 Chronology of Dispersal: All Eras: 1898 – 2007:



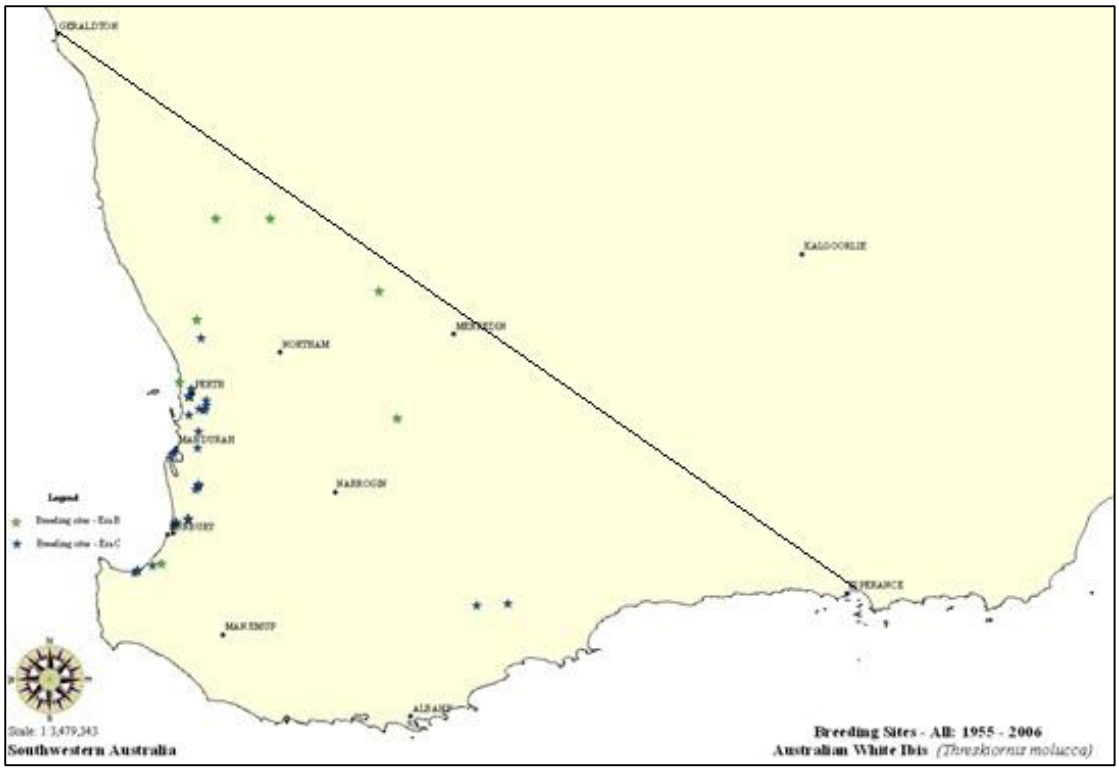
Map 5.6: Chronological Dispersal of White Ibis
(All Eras: 1898 – 2007) (No Breeding)

The presentation of all data chronologically is represented by: Era A (•) 1898-1953; Era B (•) 1954-1980; and Era C (•) 1981-2007 (Map 5.6). The map shows that subsequent to the initial incursion in Era A, 1898-1953, the majority of spread occurred linearly, north and south along the coastline.

Populations are more heavily concentrated in urbanised areas, especially larger localities such as Perth, Mandurah, Bunbury, Busselton and Albany. The initial push inland during Era B, 1954-1980, has been continued throughout Era C, 1981-2007. Despite an increase in sightings in the interior, breeding at inland sites appears to have reduced compared to Era B. This will be discussed in the following section.

The movement of the species into the southernmost sector of the study area appears a result of 'stepping-stone' dispersal across agricultural lands, eastward from Bunbury, and terminating at Albany. Whilst populations appear to be moving eastward along the southern coastline, the sightings are intermittent and do not present an unbroken line to Esperance, at the limits of the study area.

5.9.6 Breeding: All Eras 1898 – 2007:

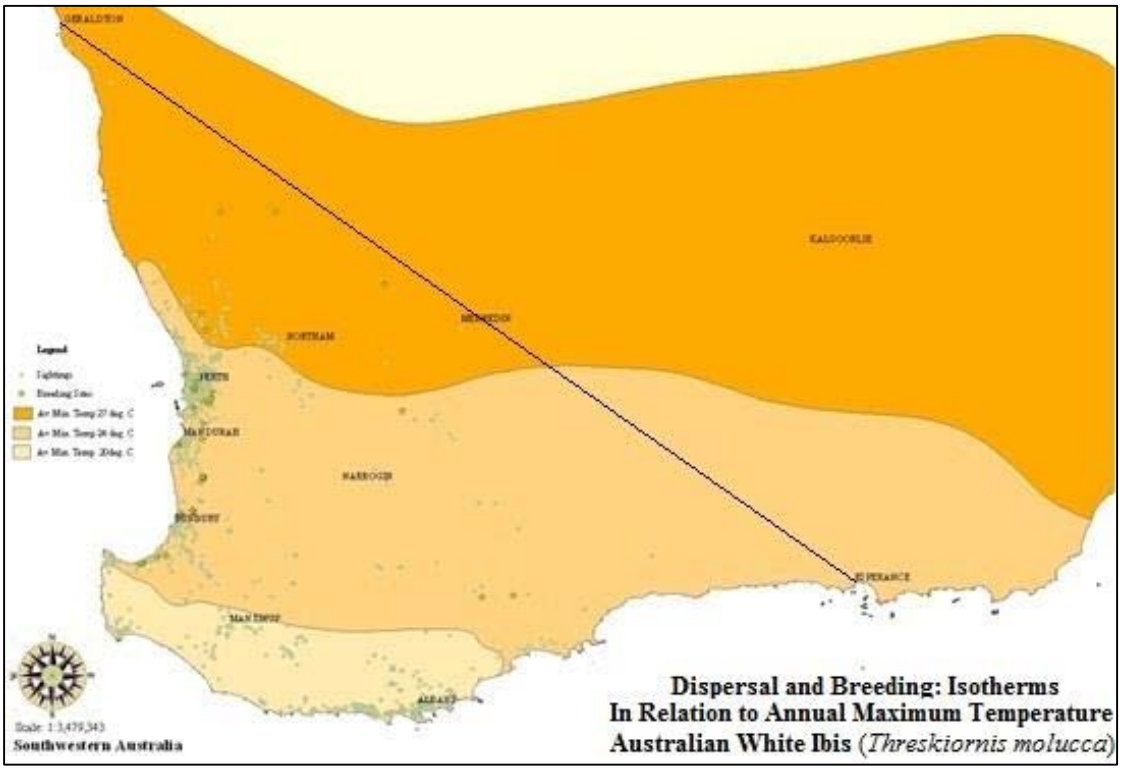


Map 5.7: Breeding: White Ibis: Era B 1954 – 1980; Era C 1981 – 2007

The presentation of all breeding data is represented by: Era B ( ) 1954-1908; and Era C ( ) 1981-2007 (Map 5.7). There are no breeding records for Era A, 1898-1953. In relation to breeding, despite reports that the species is sensitive to disturbance when breeding, the majority of breeding is occurring in intensely settled coastal urban localities.

The sites run north-south, in symmetry to the linear chain of wetlands distributed along the Swan Coastal Plain, as well as Ramsar listed sites on the Swan Coastal Plain and on the south-west peninsula at the Vasse-Wonnerup System at Busselton, south of Bunbury, reportedly one of the largest White Ibis breeding colonies in the State

5.9.7 Dispersal in Relation to Average Maximum Temperature:



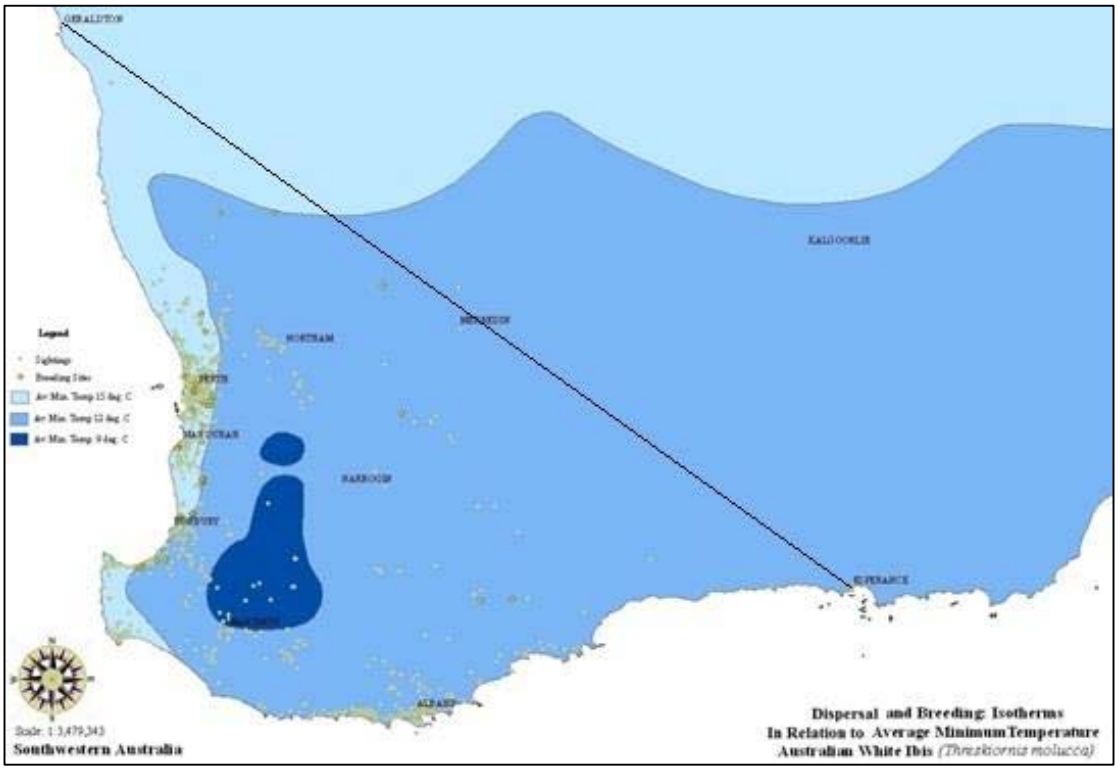
Map 5.8: Dispersal of White Ibis in relation to Average Maximum Temperature
(All Eras: 1898 – 2007) (Includes Breeding)

The data, represented as: Sightings 1898-2007 (•) Breeding 1898-2007 (☆) and Temperature zones 27°C (□); 24°C (□); and 20°C (□) (Map 5.8), shows at a glance that the dispersal of Australian White Ibis extends across all temperatures zones. The densest distribution is concentrated in the mid-range sector, (24°C) around the Perth metropolitan area and Mandurah on the Swan Coastal Plain. This is probably attributable to the accessibility of food and suitable roosting and nesting habitat, rather than an indicator of tolerance to temperature extremes.

This assumption is supported by the observation that the next densest cluster is situated in the coolest, lowest-range sector around Albany which is also highly settled and urbanised, and is a major tourist precinct. The area also provides sanctuary for rare birds and hosts extensive wetlands close to the town.

Whilst there are records displayed in the hottest, highest-range sector, they are considerably fewer and spread out in an area that is the least settled and urban. It also offers the least in terms of natural roosting and nesting habitat. Given the historical range of the species is the far north, which endures long periods of extreme maximum temperatures; it is no surprise the Ibis have adapted to cooler climes. It can be surmised therefore, that climatic matching is not intergral to colonisation success.

5.9.8 Dispersal in Relation to Average Minimum Temperature:



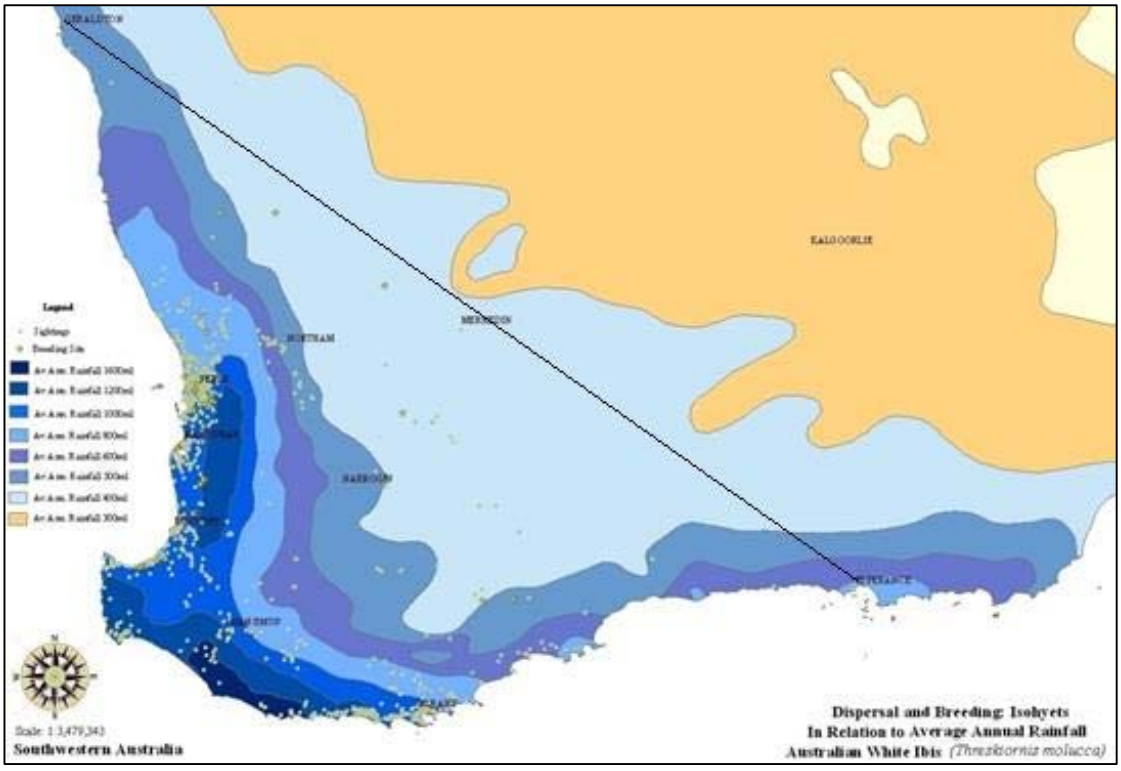
Map 5.9: Dispersal of White Ibis in relation to Average Minimum Temperature
(All Eras: 1898 – 2007) (Includes Breeding)

The data, represented as: Sightings 1898-2007 (•) Breeding 1898-2007 (☆) and Temperature zones 15°C ( ); 12°C ( ); and 09°C ( ) (Map 5.9) shows a similar distribution of White Ibis across all temperature zones in relation to minimum temperature. Whilst dispersal in relation to maximum temperature is concentrated within the mid-sector moderate zone (24°C); in relation to minimum temperature it is concentrated within the warmest zone (15°C). This zone also extends along the SCP, and the same supposition applies that this is more directly influenced by access to ecological resources, than evidencing intolerance of temperature extremes.

The 15°C average minimum temperature zone, as does the 24°C average maximum temperature zone, extends along the Swan Coastal Plain, one of the most intensely urbanised areas of the study area. Although to the south of Perth, Mandurah and Bunbury, other localities where the species are concentrated are also predominantly urban settlements.

The concentration of populations south of Mandurah is possibly linked to the Ramsar listed Peel-Yalgorup wetland system; just as that south of Bunbury, between Busselton, on the southwest corner is to the Vasse-Wonnerup system. Given that the species has colonised the coldest sector, near Manjimup, it appears temperature is not a limiting factor in the colonisation of new habitats.

5.9.9 Dispersal in Relation to Average Annual Rainfall:



Map 5.10: Dispersal of White Ibis in relation to Average Annual Rainfall (Isohyets)
(All Eras 1898 – 2007) (Includes Breeding)

The data is represented here as: Sightings 1898-2007 (•) Breeding 1898-2007 (☆) and Rainfall zones: 1600mm (□); 1200mm (□); 1000mm (□); 800mm (□); 600mm (□); and 500mm (□) 400mm (□). The arid zone (□) (≤ 300mm) falls outside of the study area limits (Map 5.10). The distribution of Australian White Ibis in relation to annual average rainfall extends across all zones. The densest distributions fall within 800-1000mm zones along the coastal belt.

The 1200mm zone that parallels the coast inland between Perth and Bunbury supports populations along its western margin; concentrated in the north-west corner; with distribution sparse around the south-east corner. Density is clustered along the coast on the upper-side of the Cape Leeuwin region of the south-west corner, in the 1000mm zone.

Southward, along the lower side, populations fall within the 1200mm zone, which extends inland into Albany where it terminates. Here, distribution is dense, clustered. The area along the south-west flank is wetter, attracting 1600mm annually, but displays fewer, more widely dispersed distributions. Inland, along the north-east margin, where rainfall reduces to 1000mm distribution is denser; similar to that of the 1200mm zone. Again, this should be viewed in relation to the proximity of the zones to settled, urbanised areas, rather than as an ecological marker for moisture tolerance.

The distribution of the data implies that White Ibis does not show a marked preference for habitat situated in the highest rainfall area (1600mm).

Conversely, with few records displayed in low rainfall zones (400-500mm), it also indicates that moisture thresholds are a limiting factor in spread for this wetland species. The distribution in relation to rainfall will now be explored in relation to breeding.

The depiction of data displays that breeding occurred deep inland at isolated sites within the 400-500mm rainfall zones. These are likely to be linked to remnant lakes systems associated with the zones of Ancient and Rejuvenated Drainage. Whilst these inland lakes range from brackish to saline, depending on rainfall, it appears White Ibis are able tolerate such harsh habitats.

Such is evidenced by their presence at brackish coastal lakes, such as Lake Josephine, a satellite lake to the hypersaline Lake Preston within the Peel-Yalgorup wetland system. Although, no eggs or nestlings have been observed there (Personal Communication, Tony France, 12 December 2007).

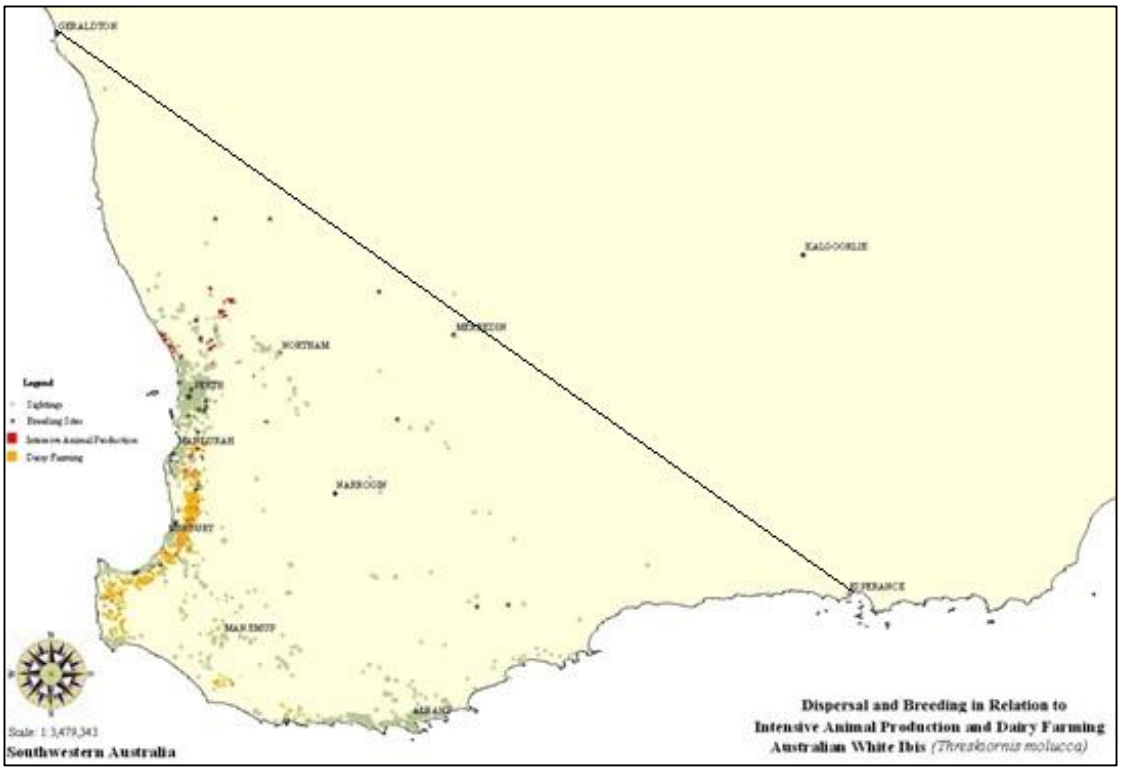
The majority of the breeding data are situated within the 800-1000mm rainfall zone; although breeding also occurred in both the 300-600mm zone and the 1200-1600mm zone. It is of interest to note that no breeding records fall within the 1600mm rainfall zone, the highest rainfall area; and overall, more breeding records are displayed in the 300-600mm zone, than the 1200-1600mm zone. Interpretation of these observable facts leads to the summation that it is the underlying hydrology of selected habitats that facilitates breeding; rather than precipitation levels *per se*.

Based on this assumption, locations for breeding are selected based on the extent of flooding at the site, with breeding commencing when inundation is suffice to isolate the nest from predators and other disturbances; the period of inundation is also critical. Seasonal timing of the flooding is less important, although optimal breeding times coincided with hatching insects and freshwater invertebrates for food.

The assertion that it is the hydrology of selected habitats rather than the levels of precipitation received that determines breeding, supports statements by Carrick (1962) that White Ibis respond to flood conditions, and have an innate sense of the "essential proximate stimulus for breeding" (Carrick 1962, p.75). With site selection a response to flooding of a suitable area, not day length, rainfall, or food supply. Although somewhat dated, this point of view has not been refuted, and so, is supported by the author of the present study.

This finalises the analyses of distributions in relation to climatic variables. Discussion now proceeds to investigation of dispersal of White Ibis in relation to anthropogenic aspects pertaining to the study area. The first characteristic for review is dispersal in relation to 'Intensive Animal Production and Dairy Farming'; as the initial incursion of White Ibis, the first point of colonisation, occurred in proximity to areas where such habitats are predominant.

5.9.10 Dispersal in Relation to Intensive Animal Production and Dairy Farming:



Map 5.11: Dispersal in relation to Intensive Animal Production and Dairy Farming
(All Eras 1898 – 2007) (Includes Breeding)

The data in relation to 'Intensive Animal Production and Dairy Farming' is represented by: Sightings 1898-2007 (•); Breeding 1898-2007 (☆); Intensive Animal Production (□); and Dairy Farming (□) (Map 5.11). It displays a plausible correlation between the dispersal of White Ibis to the specified habitats. This relates to the area south of Mandurah, inland to Pinjarra, which parallels the coast, passes through Waroona, then Coolup, one of the initial incursion sites, into Bunbury/Picton (another first incursion sites). It terminates at the bottom of the Cape Leeuwin region in the south-west corner (near Augusta), although it extends marginally into areas south-east of Bunbury toward Manjimup.

These areas, shown in orange, support extensive dairy production and pastures are irrigated year round to maintain feed for stock. The pastures cover organic soils that support an array of micro-invertebrates, insects and beetles. This includes introduced dung beetles released over successive years to aid the industry when productivity was impeded due to the inability of native dung beetles to process the dung of introduced cattle, as discussed in Eras B and C.

To the north of Perth, areas shaded in red relate to beef production. Dung beetles were released into these areas also. Whilst the pastures are not irrigated, and the environment is drier, there are permanent and semi-permanent lakes in proximity to the production areas which are not out of reach to this highly dispersive species.

Also, within the study area, in areas populations of Ibis are concentrated, there are several major cattle sale yards: at Midland, in the east metropolitan area; as well as the rural settlements of Boyanup and Brunswick (near Bunbury). Other yards are situated at Katanning, and Mount Barker, in the Shire of Plantagenet. The latter, one of the largest yards in Australia, services the Great Southern region, which is being increasingly recognised as a major cattle producing district (although it is not included on the map overlay).

However, changes in distribution of White Ibis between Era B and Era C, suggests the habitat type associated with land use in the area is well suited to the species. As there was a distinct range shift from Era B, which displays mainly coastal sightings around the greater Albany area, inland into areas around Mount Barker and surrounds by Era C.

In the south-west sector, in dairy producing districts, food is sourced from the pastures. The meadows are fed from rivers, wetlands and farm dams which are filled by precipitation and groundwater. It is unknown if the lakes are natural or not, although the lake behind appears vast for a farm dam. It is reported that "Farmers seem tolerant of the flocks…so return some benefit to the pasture at best, or have a neutral affect at the worst" (France, 2007c). These provide roosting and breeding habitats utilised by the species, although breeding is more prevalent in coastal areas (Plate 5.18 and Plate 5.19).

Plate 5.18: White Ibis, foraging, south of Waroona, WA
(France, 2007a)

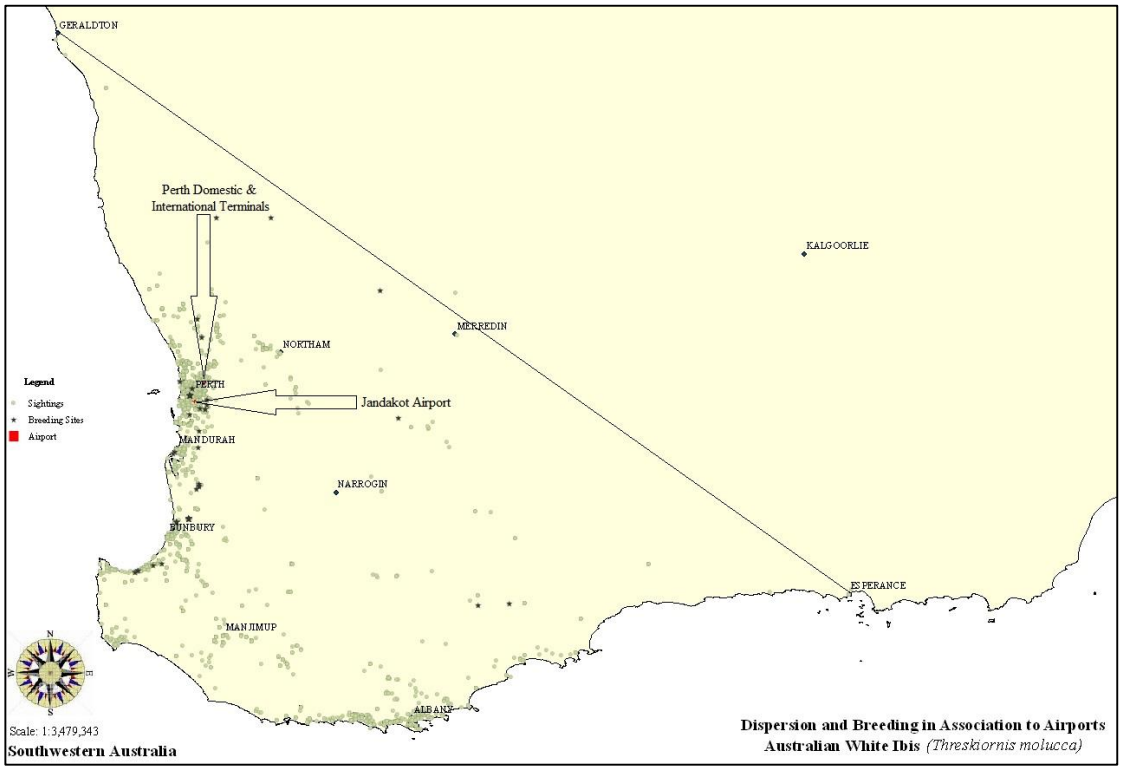
Plate 5.19: White Ibis roost, in lake, south of Waroona, WA
(France, 2007b)

It may be worth examining the extent of the species in these areas in another decade as the landscape of the area is changing. The Water Authority (WA), in partnership with private stakeholders, has begun to replace inefficient canal and waterwheel irrigation systems with underground reticulation. This could result in a retraction of manufactured wetland habitats. Also, land once used for farming is being subdivided for residential developments (2007c).

However, recent discussions with Myalup resident, Mr Tony France (Personal Communication, 12 December 2007), revealed that the impact of these changes to date, seem to have had little impact on White Ibis numbers in the district, with populations remaining constant in pastures close to farm dams and steadily increasing in the nearby ranges.

The next aspect of the dispersal of Australian White Ibis is examined in relation to major commercial airports. This feature is being included in the discussion as bird strike by Ibis represents a verified threat to aircraft, both in terms of air safety for passengers and crew, and in relation to the financial costs associated with lost productivity and costs to repair craft following bird strike. This can incur losses and expenditure that run into millions of dollars.

5.9.11 Dispersal in Relation to Major Metropolitan Airports:



Map 5.12: Dispersal of White Ibis in relation to Major Metropolitan Airports
(All Eras: 1898 – 2007) (Includes Breeding)

The distribution of Australian White Ibis in relation to major airport terminals is represented by: Sightings 1898-2007 (•); Breeding 1898-2007 (□) and Airports (□). The combined commercial passenger terminals Perth International and Perth Domestic Airport and Jandakot Airport, located south-west of the major terminals are identified (Map 5.12).

The depiction of the data shows that White Ibis populations surround each of these terminals, and therefore present a reasonable risk of bird strike to aircraft. The implications of which, are foremost, in relation to the safety for passenger and crew, and secondly the costs associated with lost productivity and repairs to aircraft following bird strike.

To reiterate information detailed previously (refer this chapter, page 112), a transport 1991-2001 safety audit listed 'ibis' (unspecified) second to eagles, as the greatest bird strike threat to aircraft safety in Australia. There were 39 incidents of aircraft strike with ibis recorded, of which 41% resulted in damage to aircraft (Australian Transport Safety Bureau, 2002).

The latest Air Transport Safety Bureau (ATSB) report for the period 2002-2011 records the total number of bird strikes involving Ibis (unspecified) at 114 (2012, p. 46) five of which occurred in WA. Whilst only minor damage resulted, given that incidents span successive decades confirms Ibis represent more than a potential threat to aircraft.

Most strikes occur between 10.00am-12.00pm. Other significant times are 6.00-8.00am and 5.00-6.00pm. This may be due to ibis feeding locally in the mornings, dispersing in the day and returning to roosts in the evening.

Whilst the latest ATSB report (2012) does not record ibis as the cause of damage to aircraft at Perth's major passenger terminals, it does list them as damaging craft at Jandakot airport, which is the busiest airport in Australia for freight and non-commercial light-aircraft (Air Services Australia, 2011, 2012).

The airport is situated in close proximity (less than 5km) to several major wetlands including Bibra, Yangebup. Thomsons Lake and Forrestdale Lake (Plate 5.20), all which have White Ibis roosts. Thomsons Lake has hosted Ibis populations that at times exceed 600 individuals (Pickering, 2012). The Canning River lies a few kilometres north of the site. Perth Domestic Airport is close to the Swan River; whereas the International Terminal is further east.

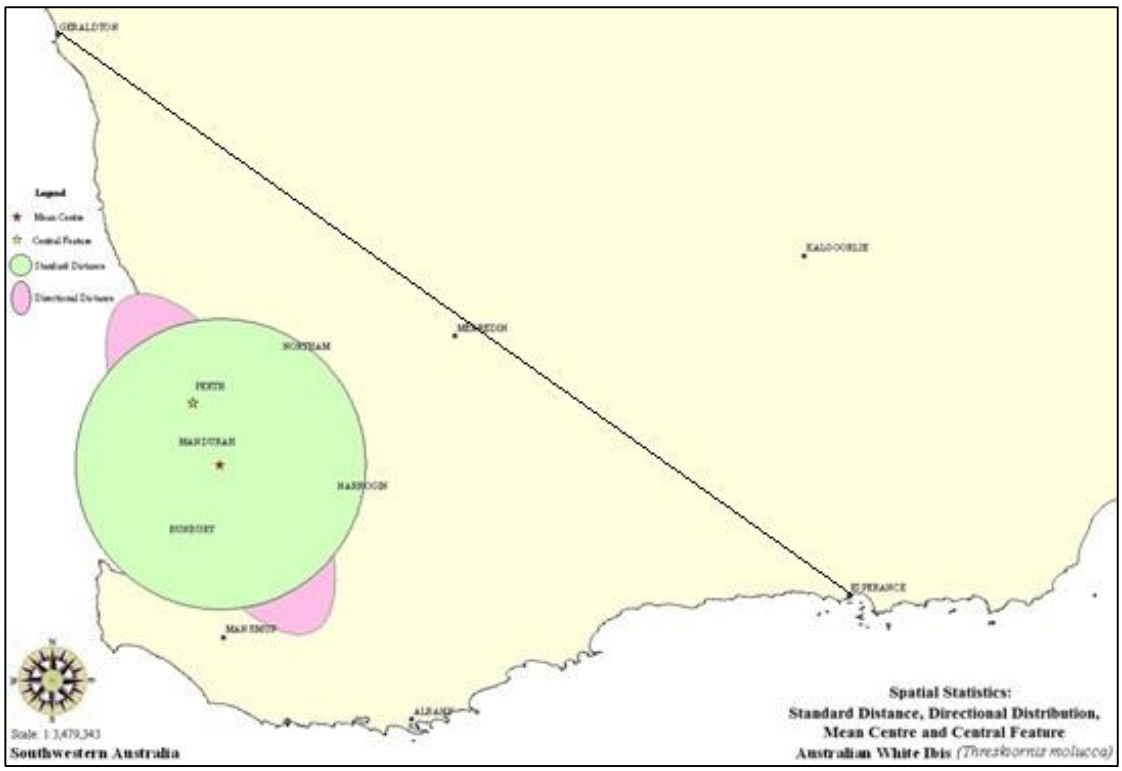
Plate 5.20: Proximity of Jandakot Airport to nearby wetlands
(Google Earth, 2013a)

There are also other regional localities that host substantial White Ibis populations that operate high traffic airports, such Albany; Bunbury; and Busselton. Other than these regional passenger and freight terminals, there are two military airbases within the study area, RAAF Pearce and Gingin. Based on data underlying the present study, the latter base is situated close to sites where White Ibis have been recorded in some number, including Lakes Bambun, Beermullah and Chittering; as well as Big Bootine Swamp. Breeding has been recorded at nearby Chandala Spring.

To date, no major air-strike incidents involving White Ibis have been recorded within the study area. However, if population growth remains as consistent as it has been since colonisation, it can be surmised that in the future, Australian White Ibis will come to represent an increased threat to private; commercial and military aircraft operating within the study area.

This concludes discussion on the dispersal of the species. *Spatial Statistics* related to the populations are now examined.

5.9.12 Spatial Statistics:



Map 5.13: *Spatial Statistics*: White Ibis
Standard Distance, *Directional Distribution*, *Mean Centre* and *Central Feature*
(All Eras 1898 – 2007)

The previous maps series appraised the dispersal of the Australian White Ibis across colonised landscape in relation to anthropogenic and geographic elements. The discussion presented here is in relation to *Spatial Statistics* associated with the populations, and includes features of '*Standard Distance*' ( ); *Directional Distribution* ( ); *Mean Centre* (★) and *Central Feature* (☆) (Map 5.13) (refer to explanations in Chapter 3, page 56).

The *Standard Distance* statistic is a measure of the extent calculated features are dispersed or concentrated. The map illustrates the main populations of White Ibis are concentrated in the mid-lower portion of the study area; capturing the intensely settled coastal strip between the northern Perth beaches and Busselton. It also extends into agricultural areas east and south-east of Perth. Several major river systems (Moore; Swan-Avon; Peel-Harvey; Leschenault; Vasse-Wonnerup; Carbanup-Toby; and Blackwood); and regionally and nationally significant wetlands (Lake Joondalup; Thomsons Lake; Forrestdale Lake; Becher Point; and Lake Toolibin) fall within the study area.

The *Directional Distribution* statistic measures whether the distribution of the features analysed exhibited a directional trend. The shaded area on the map show a population push toward the north-west and south-east of the study area. The trend could be related to the sustained urban growth along the northern corridor, fed by steadily increasing human populations in support of the mining and resources boom.

Landscape modification is extensive as new land releases are cleared for sub-division; and acreages once used for market-gardening are converted to house lots; transforming the area into urban-scape. The greater Perth metropolitan area is linking to urban outliers along the coastal strip. The trend toward the south-east reflects the species stepping-stone succession into the interior, provisioned by natural drainage features and aided by irrigation; replenishing farm dams fed from groundwater, and periodic precipitation.

The *Mean Centre* depicts the centre of concentration for a set of features; which interestingly lies just south-east of Mandurah, close to Coolup; one of the localities of the initial incursion of White Ibis into the Southwest in 1952.

Whist the *Central Feature*, which measures the most centrally located feature of the class; is situated south-west of Perth in proximity to several major wetlands. These include the Ramsar listed Thomsons Lake, Forrestdale Lake and Becher Point wetlands. Another notable site in proximity is The Spectacles wetlands. Multiple instances of breeding are recorded for the vicinity.

This concludes discussion on the *Spatial Statistics* related to the populations. The statistics related to the dispersion i.e. internal distribution of populations within the established range, will now be examined. Detailed explanations of these analyses are provided earlier (refer Chapter 3, pages 58-59).

5.9.13 Dispersion of Australian White Ibis within the Study Area:

The final aspect to the data analysis relates to changes in the spatial dispersion of the species for the Era A, 1898-1953, *Introduction, Death or Captivity* phase, Era B, 1954-1980, *Establish or Fail* phase, and Era C, 1981-2007, *Spread or Remain Local* phase of the invasion process. Dispersion, as differentiated from dispersal, relates to "the internal distribution pattern of individuals within a population" (Emmel, 1973, p. 64) and is linked to the availability of resources within the established range.

The present study firstly applied Moran's I function to the data to examine dispersion. The tool calculates spatial autocorrelation based on feature locations and feature values simultaneously by evaluating the pattern expressed. The classifications generated in the analysis are 'Clustered', 'Dispersed', or 'Random'. It calculates a Moran's Index value and *Z-Score* which signifies if a particular score is equal to, or above or below the mean score and how far it deviates from it in order to evaluate significance.

If the Moran's I index value is close to +1.0 it indicates clustering within the population; if the index value is close to -1.0 it indicates the population is dispersed. A high (positive) *Z-Score* indicates the nearby features have similar values: a low (negative) *Z-Score* indicates dissimilarity in surrounding features. The function summarises the trend of spread over space and time: is the population remaining concentrated and isolated; or expanding and disseminating. The table below (Table 5.7) shows that the data calculated (not inclusive of breeding) returned mid-range Moran's *I* values and *Z-Score* values for both Era A, and Era B, stages resulting in dispersion being classified as 'Random'. This is unusual even rare, say ecologists, for just as "we usually find non-random dispersion of resources in nature, organisms are almost never random in distribution" (Emmel, 1973, p. 64). It is suggestive that populations have not amassed suitably to fully utilise available ecological resources.

Table 5.7: Moran's **Index: White Ibis – Includes Breeding**
(Source: Present Study)

Australian White Ibis: Moran's Index: (Includes Breeding)					
Era/Group	Moran's I	**Expected**	**Variance**	***Z- Score***	**Description**
Era_A	-0.07364	-0.33333	0.23177	0.53943	Random
Era_B	0.11747	-0.00235	0.57771	0.49854	Random
Era_C	0.45776	-0.00018	0.00005	67.44246	Highly Clustered
Breeding_Era_A	-	-	-	-	-
Breeding_Era_B	0.0168	-0.16667	0.01483	1.50679	Random
Breeding_Era _C	0.02661	-0.01887	0.01333	0.39393	Random

The scores and resulting classifications are probably attributable to the low population levels throughout these stages of the invasion process: accuracy may have been inhibited by insufficient data. To contextualise, Era A, is limited to just four sightings, and arrival of the species into the study area could be a result of random selection.

Similarly, in Era B the records used in the calculation are fewer than 500. When considered in relation to the size of the study area, it is not implausible that site selection remained random; as there are a number of habitats provisioning food and roosts interspersed throughout the study area.

By the final stage of the invasion process, Era C, the number of records analysed has increased a thousand-fold, totalling more than 5500: the Moran's *I* score has almost quadrupled (3.90 times greater than for Era B); the *Z-Score* has increased 135.30 times than that of Era B, indicating a very strong similarity in the features. The classification has changed to 'Highly Clustered'; a non-random, irregular distribution of individuals in response to individuals seeking out optimal habitats.

The analysis differs extensively however when calculated in relation to breeding: Era A is not calculated (no breeding data); and Era B and Era C are both classified as 'Random' distributions due to changes in the Moran's I score and the *Z-Score*. Again, this is likely a result of the low frequency of breeding records.

When considered in relation to the size of the study area, breeding site selection based on random factors seems a reasonable assumption. However, this challenges the opinions of Lack (1966); who believes populations do not disperse randomly in any setting, most notably when breeding. His assertion that species will relocate to "a type of habitat less favourable except in being less crowded" (1966, p. 299); suggests site selection is not a response to random variables but to the extent of site suitability. So whilst spatially site selection may be classified 'Random'; it is likely the sites were selected based on their ecological suitability for breeding.

The second analysis conducted to examine the dispersion of the population was the *Average Nearest Neighbour* function; a calculation based on measuring the average distance from each feature to its nearest neighbour. If less than the average calculated for a hypothetical random distribution, features are 'Clustered'; if greater, they are 'Dispersed'. The calculation assumes all features measured are free to locate anywhere within the study area i.e. there are no barriers; and that all features are independent of one another. Results from this statistic are best when the study area is fixed. These conditions are met in the present study.

The results of this analysis are probably more reflective of the true nature of the dispersion of White Ibis populations throughout the study area. The results shown below (Table 5.8) identify that clustering of the population is evident in all but one instance (Breeding_Era_B). The *Observed Mean Distance* statistic offers the greatest insight into changes in dispersion.

Table 5.8: Average Nearest Neighbour: White Ibis – Includes Breeding
(Source: The Present Study)

Australian White Ibis: *Average Nearest Neighbour*: (Includes Breeding)					
Era/Group	***Observed Mean Distance***	**Expected Mean Distance**	**Nearest Neighbour Ratio**	***Z-Score***	**Distribution**
Era_A	0.000000	0.000000	0.000000	0.000000	–
Era_B	0.015095	0.103458	0.145902	-33.724353	Clustered
Era_C	0.003252	0.042155	0.077139	-130.944786	Clustered
Breeding_Era_A	0.000000	0.000000	0.000000	0.000000	–
Breeding_Era_B	0.888235	0.484637	1.832783	4.215138	Dispersed
Breeding_Era_C	0.034999	0.187507	0.186653	-11.434143	Clustered

This confirms that during Era B, the population is at a limit that does not demand extreme competition for available ecological resources. Individuals are able to disperse to wide-ranging locations to secure breeding sites that offer protection from predators and allow them to nest at optimal sites, at a time "food is most abundant" (Perrins & Birkhead, 1983, p. 73).

The statistics alter significantly by Era C due to exponential population growth. The *Observed Mean Distance* between individuals in Era B and that of Era C, individuals has reduced significantly as the population steadily increases.

The species is also spreading, seeking out suitable territories for roosting, feeding and breeding which have lowered availability due to increased competition between individuals for available ecological resources. The classification is consistent with the contention of Perrins and Birkhead (1983, p. 73) that the propensity of birds to flock and breed in colonies is fixed by the spatial distribution of resources i.e. access to food, and roosting and nesting sites protected from predation; as Australian White Ibis do in natural habitats.

At traditional sites feeding is rarely done in isolation; and roosting and breeding is always a colonial endeavour. Wetland habitats most suited to the ecology and habits of Ibis are not blanketed across the landscape, but confined to certain areas within the study area, resulting in the spatial clusters identified.

The limits of the present study did not allow for the dispersion of urban coastal populations to be compared against that at traditional inland sites to ascertain if the extent of clustering is markedly different in either setting. Certainly though, White Ibis are often observed alone or in pairs within urban areas; at parks café's and other precincts associated with human activity.

There were however, no incidences of individuals roosting or nesting observed throughout the study.

The habit of the species to feed solo or in pairs within urban areas perhaps displays that the species have adopted their intrinsic behaviour in order to optimise opportunities inherent in a food supply that is not limited to specific sites, but accessible in many locations: a by-product of human wastefulness.

The wide-ranging dispersal of the species across the landscape is probably attributable to their size and the physiological demand for energy to survive and breed. It is an assumed fact that larger birds defend larger areas (as per Hinde, 1956). The idea of which won further support from T.W. Schoener (1968b) who found that "territory size was directly proportional to the bird's body weight, i.e. larger species defended larger areas" (Perrins & Birkhead, 1983, p. 12).

In terms of 'Territory Type' maintained by the species, as per Hinde (1956) (as shown in Perrins and Birkhead 1983) (refer Chapter 2, page 31), Australian White Ibis, like other Threskiornithidae, do not maintain a substantial territory, either seasonally, or year round, but defend a small territory close to the nest during breeding.

It is the habit of the species to disperse long distances from the roost to feed. Such is evident in the way in which White Ibis will utilise a particular site during the day to scavenge, arriving solitarily, in pairs or in small groups, whether at a refuse site, park or place where people are gathered to eat: then, in the same manner, depart to another site, or return to the roost.

This concludes discussion on the Australian White Ibis. A summary of the main points identified within the research is now presented.

5.10 Conclusion:

Despite ambiguities associated with nomenclature, Australian White Ibis is recognised as a separate species, *Threskiornis molucca*, distinct from *T. aethiopicus*. It is distinguished from other ibis by its predominantly white plumage, which is contrasted by a black head, black-tipped flight feathers and yellow tail. It possesses a sickle-like beak effective for foraging for aquatic invertebrates, insects and beetles in its natural wetland habitats. It has proven well suited to seizing food from picnickers and diners, scavenging refuse from bins and foraging at landfill sites in urban areas.

Other problems associated with the species living in close proximity to humans relate to the odour and noise that emanates from colonial roosts, and excessive defecation over vegetation and infrastructure. They are known carriers of *Salmonella* spp and other disease pathogens. They are also a bird-strike risk to aircraft. In terms of local wildlife populations, when present in large numbers, Ibis degrade habitats, exclude competitors and push-out pre-existing populations.

Although their arrival to the study area was not aided by human transports, their colonisation and spread throughout the study area was aided by anthropogenic practice, i.e. dairy farming which irrigated pastures and created artificial wetland habitats; boosting insect and beetle numbers; effectively removing natural barriers to spread, i.e. restrictions in food availability and lack of suitable habitat. As mentioned previously, urban settlements have also provided other alternative food sources through scavenging that require less energy expenditure, for greater returns.

The modified ecology of the species is mirrored in its changing distributions. Populations have shifted from traditional inland sites to predominantly coastal urban areas. This is presenting somewhat of a conundrum for the species: with populations at inland sites declining; and urban populations growing exponentially, probably in response to their adaptive behaviour and suitability to a broad ecological niche.

Ecological adaptation of the species to the adopted landscape is displayed in the ability of the species to adjust to the cooler, moister climes of the temperate Southwest; an area interspersed with tall timbers and heath. It is a markedly different setting to that of the species historical range in the tropical Kimberley, an area set in the state's far north renowned for its harsh environment. Here vegetation is sparse and temperatures are often extremely hot throughout the prolonged 'Dry' season.

Whilst spatial autocorrelation produced varied results in terms of the internal distribution of populations, it is evident that populations are becoming increasingly clustered as population growth continues. In relation to breeding, *Average Nearest Neighbour* calculations for the initial 'Establishment' phase (Era B), classified breeding populations as dispersed; but by the 'Spread' phase of the invasion process (Era C), they had become clustered, as implied by the statistics.

The same analysis, based on sightings alone, not inclusive of breeding data, identified both Era B and Era C populations as being clustered. In ecological terms this displays a grouping of populations around available ecological resources. The extent of variability between inland and coastal populations could not be ascertained.

What is apparent from scenarios from other regions within and outside of Australia is that if sustained population growth continues in urban areas over ensuing years, it may prove problematic for residents and wildlife. Incidents involving food stealing; scavenging; the transmission of pathogens; and the fouling of amenities are set to escalate. Although not yet identified as a major pest within the study area, the potential to become one, as in the nature of White Ibis in other Australian states, and of its close, predatory relative, Sacred Ibis in Europe, looms.

In terms of the invasibility status of the species as per the 'Invasibility Rules' set down by Brown (1989) (refer Chapter 2, page 18), there are several that apply in regards to the colonisation and spread of White Ibis.

In relation to ‘Rule 1’, White Ibis have been most successful in urban habitats, characteristic of ‘Isolated environments’ that support lower species diversity and are susceptible to invasion. In association to ‘Rule 2’, Ibis is native to the Australian continent, and historically its distributions are within ‘extensive, non-isolated habitats within’ it. As for ‘Rule 3’, although the Southwest varies in climate from the Kimberley, it shares similarities with other temperate regions within Australia where the species is present, and so its introduction was ‘enhanced by similarity in the physical environment between the source and target areas’. In relation to ‘Rule 4’, its success as an invader, may not be because ‘native species do not occupy similar niches’, but because of competitive exclusion of Straw-necked, or Glossy Ibis (*Plegadis falcinellus*); and, in terms of ‘Rule 5’, the problems linked to Ibis in other parts of Australia, and Sacred Ibis in Europe, indicate these species have a history of settling ‘disturbed environments and those with a history of close association with humans’ and generally invades man-modified habitats.

In terms of ‘Territory Type’ as per Hinde (1956, as shown in Perrins & Birkhead 1983) (refer page 31), White Ibis, like other ibises, as well many other colonially nesting species, occupy ‘Type C’, functional territories: and defend a small territory around the nest.

However, when not breeding, it will fly substantial distances from the roost site to feed. This is evident in the way in which large numbers of Ibis descend on a refuse site to scour for food during the day, but do not remain there to roost at night. If there is a roost close-by, it is probably because there is suitable habitat nearby, rather than its proximity to the foraging site.

In summary, as the species has not caused enough damage or harm to yet become a ‘declared’ pest, it is perhaps in the best interest of stakeholders in public health, conservation and environmental management to promote the enhancement of natural habitats at wetland sites to draw White Ibis away from the built environment and into natural areas. This may require efforts at revegetation, to develop roosting and breeding habitats, as well as improvement of irrigation and drainage to channel brackish, eutrophic spillage away and improve site condition.

These types of ecological interventions would benefit from campaigns to increase community awareness of issues associated with the urban blight of Ibis i.e. educate people not to hand feed wildlife, and to dispose of refuse properly e.g. bin it in public areas, or compost or wrap organic refuse at home, and keep rubbish bins covered and lids secured. Local authorities could develop a coordinated approach at refuse sites to deter Ibis e.g. establish regimes to cover or bury food waste promptly; and use audio-scaring to unsettle them and move them on.

At this juncture, it is probably premature to consider reducing urban-coastal populations by means of ecological controls; such as the destruction or removal of nests and eggs, and egg oiling. However, the study area supports several wetlands of global significance protected under the Ramsar Convention, some which host globally migrating water-bird species, also protected under international treaties. It is therefore paramount, that as citizens, by thought and in deed, we do what is necessary to protect them from being displaced by this urban usurper.

6 CONTRASTING COLONISERS: *STREPTOPELIA* DOVES

Spotted Dove (*S. chinensis*) & Laughing Dove (*S. senegalensis*)

6.1 Nomenclature and Taxonomy:

This chapter adopts a comparative approach in the examination of differences between the patterns of dispersal of the Spotted Dove (*Streptopelia chinensis*), and the Laughing Dove (*S. senegalensis*) subsequent to their colonisation of the study area. Such an approach allows for discussion as to why the distributions of these two closely related species, with similar ecological requirements and release histories (*circa* 1898-99), differ to such an extent.

Both belong to the Family Columbidae, pigeons and doves: names which are interchangeable as they do not refer to distinct features, but rather, a group of characteristics. Both are classified under the genus, *Streptopelia* and display such striking similarities that a recent study of molecular gene sequence and vocalisation based on several thousand samples (2001) classified them together as belonging to one of three distinct groups: (i) *S. chinensis* plus *S. senegalensis*, (ii) *S. picturata* plus *Nesoenas mayeri*, and (iii) all other species of *Streptopelia*. This close relationship of *S. chinensis* and *S. senegalensis* had formerly been realised by Nowak (1975) and Goodwin (1983). The discovery that both were differentiated from other *Streptopelia* taxa has led successive authors to classify them separately.

In his work, zoologist Carl Sundevall (1872) classified *Stigmatopelia* to include *senegalensis*; and *Spilopelia* to incorporate *chinensis*, *suratensis* and *tigrina* (at the time treated as separate species). All were listed on the same page of his book, which caused some authors to adopt *Stigmatopelia*, as it was listed first (Cheke, 2005). However, Schodde and Mason (1997) in their catalogue of Australian birds adopted the genus name *Spilopelia* on the basis of Article 24(b) of the ICZN Code (International Commitee for Zoological Nomenclature, 1985), the 'Application of the Principle of the First Reviser'; clause, in deference to the first reviser.

For the study the nomenclature of Christidis and Boles (1994, 2008) is adopted. To clarify, Checklist (1994), lists both species as 'Turtle-Dove' which was changed to 'Dove' in Checklist (2008). From this point forward in the study, the species referred to as Spotted Dove relates to *Streptopelia chinensis*, and, Laughing Dove, to *Streptopelia senegalensis*. However, it is widely accepted that the Perth specimens of the Spotted Dove "show characteristics of two subspecies *S. c. chinensis* and *S. c. tigrina* (Johnstone, 1998, p. 257). Hybridisation amongst *Streptopelia* species is common and has been well documented (Blakers *et al.*, 1984; Davies, 1967; Irwin & Cole, 1936; Irwin & Cumley, 1945; McCarthy, 2006).

Historically, it has been well documented that some *Streptopelia* species have adapted well to environments modified by humans and have expanded their range (e.g. *S. decaocto*; Bijlsma, 1988; Hengeveld, 1993; Hengeveld & Van Den Bosch, 1991; Kasparek, 1996). Conversely, others maintain remarkably localised distributions (e.g. *S. hypopyrrha*). Such a contrast is presented in the following discussion.

6.2 Physical Characteristics:

There are a number of characteristics common to the Genus shared by both species: the black bill has a swollen hard tip and soft basal portion (cere) to house the nostrils, which although open, have an operculum. The legs are covered in hexagonal scales and feathered on the upper part. There are four toes, always of the same level. (Robinson, 1927). The plumage is pastel with splashes of vivid colour or iridescence. Flight is signalled by noisy, rapid take-off. The voice is soft, courtship graceful and mating rituals display "an appealing gentleness" (MacDonald, 1973, p. 196).

Of the two *Streptopelia* species featured here the Spotted Dove is bigger at 27-34cm in length and weighing 116-205g. As the name suggests the neck displays "a black patch spotted with white" (Storr & Johnstone, 1979, p. 143). The rest of the plumage is plain with the upper body grey-brown; wings and back brown. The upper wing-coverts display a "central dark stripe and lighter edges" (Long, 1981, p. 220). The eye skin is purplish, chin whitish and throat and breast purplish-pink. Juveniles are muted in tone with a brownish bill and lack the spotted collar (Johnstone, 1998) (Plate 6.1).

It is a sedentary and usually solitary species but at times forms small groups and congregates at food sources. Whilst the voice of both species is similar, they vary slightly; with the Spotted Dove said to have the harsher call, a "*Musical, drowsy*, coo, coo croo-oo *or* coocoo, croo-croor, *for advertising*" (Schodde & Tidemann, 2003, p. 250) with the final note drawn-out.

Plate 6.1: The Spotted Dove (*Streptopelia chinensis*)
(Tate, 2008l)

The smaller Laughing Dove grows to 21.5-28cm and 64-134g. The upper body is "toned lilac" (Long, 1981, p. 222), with the head a purplish-grey and the throat and neck offset by a "mottled reddish brown and grey" mantle and part wing. The rest of the wing as well as the back are blue-grey and the tail dark grey with a white tip. The front of the neck is reddish-brown and "speckled with black" (1979 p. 145). The breast is purplish-brown breast and white flourishes show on the belly and under the tail coverts. The iris is dark brown (Plate 6.2).

Immature birds also differ in colouration, and are more reddish-brown than lilac-hued. They also lack the blue-grey wing patch and neck patch. The plumage also changes in older birds, which display rusty brown tips on the scapular and inner upper-wing converts and the mid-foreneck and breast dull to a brownish purple. They also lack the mottled black and reddish brown gorget.

Like the Spotted Dove, it is also sedentary, but is more social and often seen in pairs and small flocks. Their call is softer, although more incessant, possessing a "*laughing quality*" (Schodde & Tidemann, 2003, p. 251); hence its namesake.

Plate 6.2: The Laughing Dove (*Streptopelia senegalensis*)
(McDermott, 2007)

6.3 Habitat and Food:

The successful range expansion of Columbidae worldwide is attributable to the adaptability of the species "and the readiness with which many accept the human environment" (MacDonald, 1973, p. 196). More so, the species have successfully adapted to a diverse range of environmental conditions which in some instances vary greatly from the habitat of their place of origin, moving from rain forest into deserts, devoid of trees, just so long as seed, fruit and berries are accessible.

These predominantly vegetarian species feed mainly on seeds or fruits which are sometimes swallowed whole (Robinson, 1927). As hard desert seeds form a major part of the diet, regular water intake is demanded. A characteristic of dry country species, such as the Laughing Dove "is the rhythm of their drinking habits and the amount they can consume at a time" (MacDonald, 1973, p. 196).

Drinking times for both are usually at sunrise and sunset, when the species is least vulnerable to predation. As a further defence, they will sometimes arrive and depart the water supply in flocks. The drinking action is unusual amongst birds, as it involves almost full immersion of the bill, allowing it to drink deeply; not sip, as is characteristic of most other species (Plate 6.3). Once hydrated both species are capable of dispersing widely and for long distances to feed and to breed.

Plate 6.3: The Laughing Dove, drinking
(Note the full immersion of the bill)
(Singhal, 2012)

In its native range of Southern Asia, the Spotted Dove is common to habitat synonymous with "open country and sandy plains with patches of short grass surrounded by bushes" (Robinson, 1927, p. 61). It usually avoids hilly areas, jungle and mangroves. It is common around rice fields, especially those bordered by trees.

In its adopted range within Australia, it is found in open forest areas, as well as wooded and cultivated landscapes such as parks, rivers and urban residential areas. Its diet is mainly "seeds, grains, green shoots and food scraps" (Long 1981, p.220), although it is known to eat figs (Barker & Vestjens, 1989; Lepschi, 1997), specifically 'Moraceae', the damaged fruit of Rock Fig (*Ficus platypoda*).

The Laughing Dove is also an inhabitant of "woodlands, towns, villages, parks, gardens and cultivated areas" (Long, 1981, p. 223). However this species, says Barker and Vestjens (1989), has a more restricted diet consisting mainly of "seeds and grains". Although the Laughing Dove has been recorded taking damaged Rock Fig (*Ficus platypoda*) fruit and olives (*Olea europaea*) (Lepschi, 1997). The taking of figs by the species is also reported in Storr (1965, p. 174), who tells of a flock of Laughing Doves on Rottnest Island "feeding on the fallen fruits of a Moreton Bay Fig" (*Ficus macrophylla*)". Although it was August, the end of winter, a time other preferred foods may have been scarce.

Although both species will eat fruit, seeds and grains are the main dietary staples (Barker & Vestjens, 1989) (Table 6.1). Plant species related to those listed below that grow in the study area are listed in the Appendices (Appendix 7). Many of these species grow kerbside, on verges, and in wastelands. Some examples are shown below (Plate 6.4).

Table 6.1: Food types of the *Streptopelia* Doves
(Barker & Vestjens, 1989)

FOOD TYPES OF SPOTTED DOVE AND LAUGHING DOVE (Barker & Vestjens, 1989)			
Spotted Dove *(S. chinensis)*		**Laughing Dove** *(S. senegalensis)*	
poultry pellets		poultry pellets	
corms		corms	
bread		Bread	
Avena sativa	grass seed	*Avena sativ*	grass seed
Cynodon sp	seed	*Cynodon* sp	seed
Eleusine sp	seed	*Eleusine* sp	seed
Hordeum sp	seed	*Hordeum* sp	seed
Poa annua	seed	*Poa* sp	seed
Poa sp	seed	*Sorghum vulgare*	seed
Sorghum vulgare	seed	*Triticum aestivum*	seed
Triticum aestivum	seed	*Helianthus annuus*	seed
Zea mays	seed	*Phlox* sp	seed
Arctotheca nivea	seed	*Stellaria media*	seed
Helianthus annuus	seed	*Arachis hypogea*	seed
Phlox sp	seed	*Ficus macrophylla*	fruit
Stellaria media	seed	*Olea* sp	fruit
Arachis hypogea	seed	*Rumex* sp	
Cajanus cajan	seed		
Quercus palustris	acorns		
Acacia sp	seed		
Ficus sp	fruit		
Rumex sp			

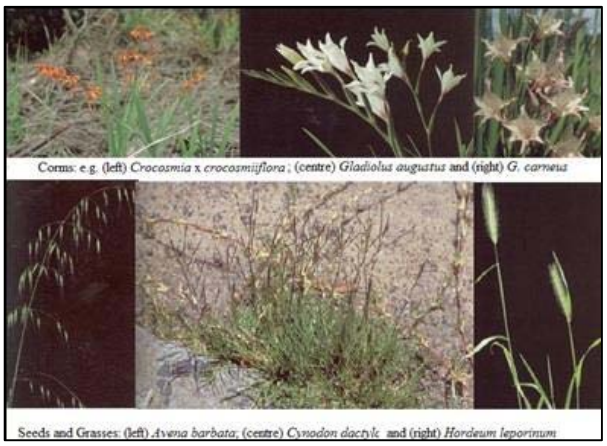


Plate 6.4: Food of *Streptopelia* doves common to the Study Area
(Adapted from: Hussey *et al.*, 1997)

The findings of Barker and Vestjens (1989) are similar to Frith, McKean and Braithwaite (1975), who investigated food consumption by *Streptopelia* doves in Sydney, Melbourne and Perth. The main difference is that the earlier study lists 'animals' (not specified) as a food source, which the latter does not. The category, which accounts for only a very small percentage of overall dietary intakes, is much higher for the Spotted Dove (2.7%) than the Laughing Dove (0.3%) (1975, p. 17).

The research of Frith *et al.* included a monthly analysis of the main foods eaten to identify seasonal variations in diet. The results show the extent to which both species utilise domestic animal feed as food. The mean annual percentile is marginally higher for the Spotted Dove (45.7%) than Laughing Dove (44.2%) (1975, p. 16). Note that sampling by Frith *et al.* was restricted to urban populations (Table 6.2).

Table 6.2: Other foods of *Streptopelia* doves
(Frith, McKean and Braithwaite, 1975)

Other foods of *Streptopelia d*oves, Perth, Western Australia (Frith *et al.*, 1975)														
Species	**Food Source**	**Composition of Food (%)**												
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean %**
Spotted Dove	Domestic Animal Feed	72	41	49	53	18	29	40	49	60	43	54	40	45.7
	Bread	5	4	8	11	4	14	37	16	7	8	9	20	11.9
	Garden and Wasteland	23	55	43	36	78	57	23	35	33	49	37	40	42.4
	Size of Sample	20	22	25	15	13	17	15	11	21	20	19	21	219
Laughing Dove	Domestic Animal Feed	43	27	33	35	0	67	31	38	48	43	50	70	44.2
	Bread	20	28	51	17	0	33	52	41	47	38	9	10	31.3
	Garden and Wasteland	37	45	16	48	0	0	17	21	5	19	41	20	20.45
	Size of Sample	19	14	15	6	0	5	15	14	14	18	18	19	157

Other trends indicate that the Spotted Dove eats less bread than the Laughing Dove and is most reliant on it as a food source in July, in mid-winter, a time when food sourced from gardens and wastelands is at its reduced. There is an equally low percentage for this food type taken in mid-summer, in January, that corresponds to the highest percentile of domestic animal feed consumption (food for domestic and zoo animals).

The ‘Domestic Animal Feed’ category includes wheat, sorghum, oats, sunflower seed, maize, pigeon peas, peanuts and high-protein poultry pellets. Of these, wheat was the primary food source. It was taken by almost 40% of the sample group and accounts for about 30% of the overall food intake (Frith *et al*., 1975, p. 18).

The consumption of domestic animal feed for the Laughing Dove peaks in December at the start of summer, and again in June at the start of winter; although it is eaten most of the year. A survey respondent recalls that when he fed his chickens from an uncovered location outside, up to 30-40 Laughing Doves came to feed (Spotted Dove only came occasionally). When the feed was moved inside an aviary they fed from there at first but sometimes became trapped and died. Gradually fewer and fewer came until only one or two doves remained. The amount of poultry feed being consumed also dropped significantly, indicating that most of it was being eaten by the doves (Personal Communication, Ron Van Delft, 01 December 2007).

Bread is eaten throughout the year but peaks in mid-winter in July. And from the ‘Garden and Wasteland’ category are eaten mainly from November to April, reaching a peak in April after autumn rains. The consumption of these foods November through to February corresponds seasonally with the seeding of exotic grasses.

Another report by R.H. Stranger, (1969) of the Spotted Dove on Mandurah foreshore, recalls it feeding near Sea Rocket (*Cakile maritima*) and Strand Daisy (*Arctotheca nivea*), both that were flowering and seeding. He thinks it unlikely the dove could access the seeds of the Sea Rocket pod and was feeding on Strand Daisy. The same report lists the Spotted Dove feeding on seeded Winter Grass (*Poa annua*).

6.4 Breeding:

Like all Columbidae both Spotted Dove Laughing Dove are monogamous: they may pair for a season, or in some cases, a lifetime. The young, called ‘squabs’ (Sheppard, 1989) hatch sparsely downed and remain in the nest for a long time. At first they are fed with a digested regurgitated secretion from the crop of the adults known as ‘crop milk’ (Robinson, 1927); it is produced by both the male and female.

The cheese-like secretion is produced in the epithelial cells that line the crop, and is formed as it sloughs off the crop wall. Its purpose is to provide an alternative to solid foods, mainly seeds and grains, which the young cannot process (Kameda, 1996). Analysis has shown it to contain 28% dry matter, 58.6% protein, 33.8% fat, 4.6% ash and 3.9% starch (in the dry matter). The crop milk is said to be “very similar to that provided by the egg before hatching” (Davies, 1939, p. 901).

As with all doves and pigeons the clutch size of both the species’ is small and does not vary. This ecological disadvantage is however overcome by the ability of species to produce crop milk all year round, resulting in them producing “small constant clutches in an extended breeding season” (Kameda, 1996, p. 51).

The ability to do so is thought to have assisted their settlement of varied habitats throughout the world and is attributed to the expanding abundance and spread of the species.

Whilst the courtship displays of both species share some similarities, they are subtly different. The Spotted Dove display is signalled by “steep upward flight with clapping wings” (Johnstone, 1998, p. 259); to about 30-50m above the perch, then followed by a gliding descent with wings and tail spread. Upon landing the male coos and bows and the throat, neck and tail feathers are raised to display the collar (Plate 6.5and Plate 6.6). Allopreening, although not stipulated as a courtship ritual is sometimes undertaken prior to pairing and copulation.

Plate 6.5: Spotted Dove, mating display
(Singh, 2013)

Plate 6.6: Laughing Dove, courtship display
(Ravinarayaha, 2009)

The nest of a Spotted Dove has been described as a “rough platform of sticks in a bush or on buildings” (Long, 1981, p. 220), and “a frail platform of sticks and rootlets” (Schodde & Tidemann, 2003, p. 250). Often rhizome roots are used in construction. The size of the nest varies between 150-200mm in diameter. The clutch is usually limited to two shiny white eggs about 29 x 23mm. Incubation of the eggs is carried out by both parents and lasts 14-16 days. The young fledge at about 15 days (Plate 6.7and Plate 6.8)

Plate 6.7:Sotted Dove, Squab and Egg
(Dunis, 2005)

Plate 6.8: Spotted Dove, Juvenile
(Sanny, 2012)

Other than being a monogamous species, the Laughing Dove is also an 'anniversary nester' i.e. tends to return to the same nest site each year (Boukhriss & Selmi, 2009). The flight display by the male includes noisy wing beats as it launches from a perch, flight to a fair height, then descent with the wings and tail spread wide. During the courtship the male bobs its head rapidly and coos gently with the collar puffed in obvious display. Sometimes before copulation, the female will transfer food into the bill of the courting male.

The nest of the smaller Laughing Dove is a "scanty platform of twigs and sticks" (Long, 1981, p. 223) that appears more frail than the nest of the Spotted Dove. It is about 150mm in diameter and is sometimes lined (Plate 6.9). The clutch is usually two eggs, but sometimes three. A report in Serventy and Whittell (1967, p. 245) stipulates a 35 hour interval between the laying of each egg, "the first being laid late in the evening and the second in the morning". Incubation is 14-16 days, by both male and female. The young do not fledge for up to 21 days.

The main points of difference between the species in relation to breeding are: the Spotted Dove nests are bigger and constructed of sturdier materials, possibly due to their larger body mass. The Laughing Dove sometimes produce three eggs per clutch whilst the Spotted Dove generally only lays two; and Laughing Dove chicks fledge one week later (at 21 days), than the Spotted Dove (at 15 days).

Plate 6.9: Laughing Dove, nesting
(Note the structure, a 'frail platform of 'fine' sticks')
(Heyns, 2012)

Several survey responses report breeding by both species in suburban parks and gardens, often in exotic trees, shrubs and creepers such as Leylandii Cypress (*Cupressocyparis leylandii)*, Tasmanian Blue Gum (*Eucalypts globulus*), Bracelet Honey Myrtle (*melaleuca armillaris*), Apricot (*Prunus armeniaca*) and *Lonicera* spp (Honeysuckle). Such was evidenced in one survey response that detailed how a pair of Laughing Doves had nested in an "unidentified creeper, probably exotic" and "raised three young" (Pers. Comm. G.B. Wingrave, 10 January 2008). Other ecological adaptations to existing in urban habitat include nesting in hanging-baskets and other built structures (Plate 6.10; Plate 6.11 and Plate 6.12).

Plate 6.10: Spotted Dove, nesting in hanging basket
(Moon, 2007b)

Plate 6.11: A Laughing Dove, nesting in hanging basket
(Tate, 2008f)

Plate 6.12: Laughing Dove, nesting in an electrical fitting
(Hythumm, 2011)

Within Australia, breeding by *Streptopelia* doves, is variable according to Long (1981), and may occur throughout the year if conditions are favourable. This is not surprising given that in their countries of origin, the species breed all year. To date records have been unable to identify peak breeding times. In Burma, writes Smythies (1953), the species breeds throughout the year, as in Borneo, although here there is increased breeding in upland populations during September-March (Smythies, 1960). Similarly, in India, states Ali (1964), breeding occurs for most of the year

Throughout Africa, breeding times differ: In Malawi, breeding occurs in all seasons; in Zimbabwe (formerly Rhodesia) mainly May-November, as well as at other times also. In South Africa, breeding takes place at least August-April and in Tunisia and Egypt, between February-June (Etchécopar & Hüe, 1967). In the United States, breeding extends March-November, and in Hawaii, February-October.

Research on the sexual cycles of *Streptopelia* doves in Australia, examining "factors controlling breeding in species living in urban environments", (Frith *et al.*, 1975, p. 15) found that geographic variance in breeding times between States, in localities where food is abundant, was more due to "different genetic composition of the populations", than food supply. It identified that whilst many males produce sperm and many females have enlarged ovaries each month of the year, gonad size varied throughout. The majority of growth occurred in spring-summer; and the least amount in autumn-winter. The findings mirror those of Serventy and Whittell (1951) that whilst *S. chinensis* breeds mainly in spring-summer, it also breeds throughout the year, with nests found in each month.

In summary, the authors hypothesised that whilst the gonadal cycles of both species were significantly impacted by "fixed annual factors, including photoperiodic effects and by environmental factors including food" (Frith *et al.*, 1975, p. 23), the nutrition levels of urban populations was often above the threshold that triggers breeding. Therefore differences in gonadal cycle and the period of breeding between cities could be possibly attributed to unidentified environmental factors or differences in genetic composition of the geographically diverse populations. How these findings compare to those of the present study is now presented for discussion.

Results drawn from the present study clearly support Frith *et al.* (1975) (Figure 6.1 and Figure 6.2). That is breeding does occur the year through, although mostly during Spring-Summer. In consideration of breeding, the Spotted Dove in particular has aligned itself to urban habitat so the trend to breed during this interval is probably not linked primarily to food availability but other environmental factors. For although the abundance of food i.e. from hand-feeding and food scraps may decrease during winter as people spend less time outdoors, other foods remain accessible year round i.e. poultry and pet feed, and from bird-feeders.

For the Spotted Dove, the lowest breeding incidences are recorded during autumn, in April-May. Factors that may explain this include declining surface water and food supply. As at this time of year wetlands, lakes and damplands have evaporated throughout Spring-Summer. Also, naturally occurring foods (seeds and fruits) are scarce and food stuffs from the previous season are not plentiful enough to be viable. Also, at this time, the physical condition of the species is less than optimal for breeding. Breeding demands peak physical condition, fuelled by high levels of protein intake and access to moisture. At the close of summer, when food stocks are low and surface water diminished, their physical condition is less than ideal for breeding.

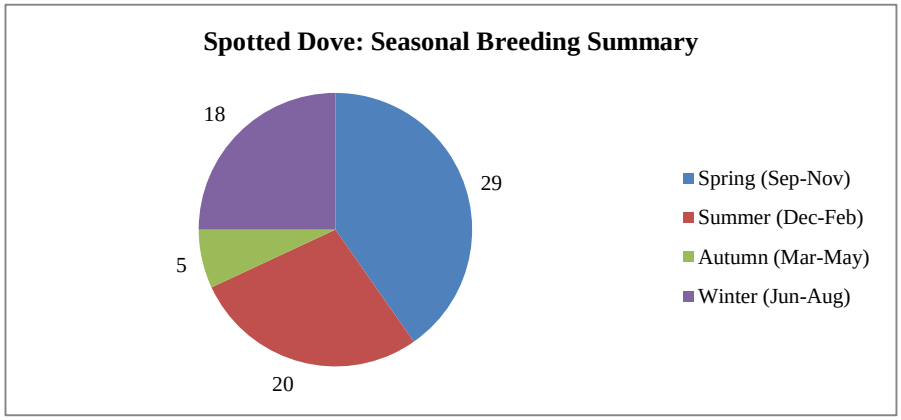


Figure 6.1: Spotted Dove: Seasonal breeding summary
(Derived from Present Study)

Breeding by the Laughing Dove displays similar peaks and troughs. Whilst the majority of breeding occurs throughout Spring-Summer, it also occurs at other times of the year. Reproduction during autumn exceeds that of the Spotted Dove. Another point of difference is that breeding occurs outside of urban precincts where food and water must be more actively sought. These factors suggest the Laughing Dove is not only able to sustain the physical condition demanded of breeding following summer, but can maintain supply of sufficient food and water to nourish the young in harsh environmental conditions.

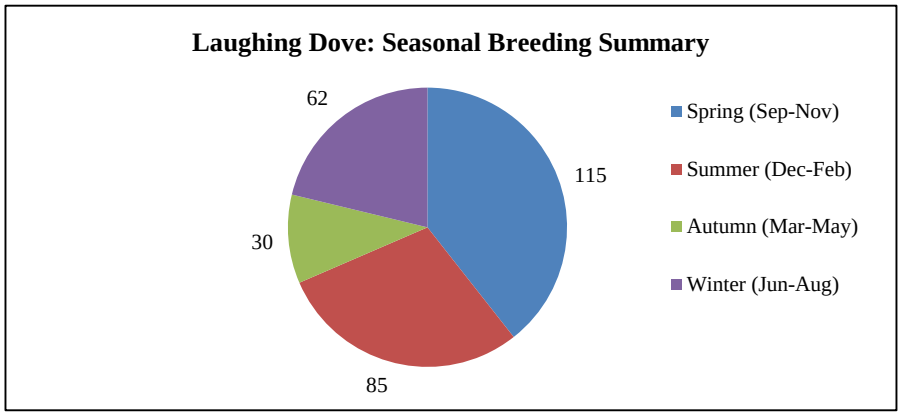


Figure 6.2: Laughing Dove: Seasonal breeding summary
(Derived from Present Study)

6.5 Status of the Species in other States and Territories:

Just as the Spotted Dove and the Laughing Dove were released in Western Australia for no other than aesthetic reasons, so too were they released into other Australian states. The first Australian release of the Spotted Dove, from its China and Indo-Malaysia origins, relate to those trans-located to Melbourne in the 1860s with subsequent releases taking place in Adelaide (1881) and Perth (1898) (Blakers *et al.*, 1984).

On the east coast, the Spotted Dove colonised well and spread widely. It reached Sydney by 1898, Brisbane by 1913, and Townsville (far north Queensland) by 1926. Later sightings in Cairns and Innisfail in 1945 were probably birds of a separate importation as they are "are almost pure *tigrina*" (Blakers *et al.*, 1984, p. 222), unlike most other Australian populations which are *S. chinensis* and *S. tigrina* hybrids.

A report by Boehm (1961) suggests that in South Australia the Spotted Dove escaped or were freed from the Adelaide Zoo (possibly during a storm). Within two decades it had established and spread widely across the city. In 1881 a further twenty were released from Adelaide Botanical Gardens, further bolstering (colonising) numbers. By 1953 they had crossed the strait to reach Kangaroo Island, and by 1966 had traversed inhospitable mallee country to establish in the Eyre Peninsula.

However, Spotted Dove populations occur in isolation in the State and are probably linked to locally liberated birds. Sightings in Waikerie and Berri "seem likely to be the result of the crossing of a rather unfavourable mallee habitat" (Chapman, 1966). The fact that the species has crossed desert and the sea suggests they are capable of long range dispersal across inhospitable habitat. As a general rule though, populations have remained limited to urban centres, including "Adelaide, Adelaide Plains and Mt Lofty, north to Clare (60 miles) and south to Victor Harbour (60 miles)" (Tarr, 1950, p. 191); approximately 100km from the city.

In Victoria, after the first liberation of the Spotted Dove in the 1860s, there were subsequent releases near Melbourne from 1872-1874. By the 1950s the species was present "in large numbers in the parks and gardens of Melbourne" (Tarr, 1950, p. 190) and had dispersed into outlying areas, having breached Sherbrooke Forest, Kallista, Geelong, Ballarat, Macedon and Mornington. Its distribution limit though is estimated at "100 miles radius of Melbourne", or 160km of the city (1950, p. 190).

Similarly, in New South Wales, Tarr (1950, p. 190) lists the species as "very common in the Sydney area and some other large towns". Again, it remains rare in country areas, with only a single sighting recorded at Moree (McGill, 1944, p. 62). Despite the ensuing decades, Long (1981, p. 222) lists its populations as abundant around Sydney and "in most coastal settled areas", with no advances into rural areas.

Other than the spread of the Spotted Dove from the south into Queensland, there were other deliberate releases including Brisbane 1912, after which the species colonised the Botanical Gardens of Queensland University by 1913.

Another release occurred at Gordonvale in the mid-1940s. It has since penetrated forested areas, where it is considered as much as a pest as it is in urban centres.

In Tasmania the species is limited to coastal populations around Hobart and Launceston. As in mainland States, the Spotted Dove has failed to colonise rural areas and remains rare "with only a few to be observed" (Tarr, 1950, p. 191).

Liberated populations of the Spotted Dove, mainly hybridised progeny of *S. chinensis* and the sub-species *S. tigrina*, were once limited to coastal areas from Queensland to South Australia. As stated previously, it is most likely that all existing populations are hybrids, with "probably no pure stocks of this race in any mainland State" (Long, 1981, p. 222). Their spread though has been described as "slow, involving advances and retreats rather than a steady expansion" (Blakers *et al.*, 1984, p. 222), assisted by later releases well into the 1970s.

However, both species have since colonised parts of the Northern Territory although the Laughing Dove populations are limited (Norris & Low, 2005). In Alice Springs though, following the liberation of approximately 10 birds from a backyard aviary, the Spotted Dove has established a permanent population which now exceeds 8000 (Bagnara, 2009). It is classified a high-extreme pest threat due to its fouling of infrastructure and incessant cooing. It is also seen as a threat to native species arising from competition for ecological resources, and a threat to farmed bird industries as it hosts parasites and disease. Culling has commenced to reduce their numbers.

Throughout the rest of Australia the increasing abundance of the Spotted Dove has resulted in its classification as a minor pest. Mainly due to its habit of scavenging at cafés and in parks and gardens where it also fouls buildings, surfaces and infrastructure. It pilfers poultry feed and spreads stickfast flea (*Echidnophaga gallinaceae*). It is also a recognised pest at garden centres, especially plant nurseries, where it damages plants and strips pine and vegetable seedlings.

Most alarmingly however, in Victoria and South Australia, the Spotted Dove has become so abundant that it has excluded populations of native Peaceful Dove (*Geopelia striata*) (Pizzey & Knight, 1997). Fears of a similar scenario developing in the Northern Territory have also been documented, both in relation to the Spotted Dove and the Laughing Dove (Bagnara, 2009; Norris & Low, 2005).

The ability of the Spotted Dove to adapt to human modified habitats has made it a successful urban coloniser. It has adapted by utilising built structures to shelter and nest, and foraging for food stuffs left by people. However its dependence on these urban provisions has limited its spread into natural and rural environments.

Whilst the Spotted Dove has established robust populations almost Australia wide, including metropolitan Perth, the spread of the Laughing Dove has been most successful within the study area; the area to which it was introduced first (Blakers *et al.*, 1984).

Although it was later released in Sydney, Toowoomba, South Australia and Queensland in the 1940s (Chapman, 1966; Long, 1981; Tarr, 1950), it failed to establish permanent populations and populations in these locations remain patchy.

Whilst these differences in the extent of colonisation success of Laughing Dove in the localities they were released could be attributable to the frequency of releases and the numbers liberated, there are other considerations. For example, in Victoria, New South Wales and Queensland, although the Laughing Dove colonised successfully, their numbers quickly declined, possibly due to competitive exclusion by another introduced species, Common Myna (*Acridotheres tristis*). Similarly, in South Australia, the failure of the species to colonise widely has been linked to ecological competition with Common Starling (*Sturnus vulgaris*) (Kitching, 1986).

The study area is the only place both *Streptopelia* doves coexist. Here the Laughing Dove has spread into urban and regional localities and their distribution now extends several hundred kilometres to Geraldton, Merredin and Esperance. Populations at these isolated outliers though, may be a result of independent releases, rather than offspring of the parent populations released. Since establishing in these regional localities within the study area boundaries, it has pushed further inland into the arid interior and has been recorded at Kalgoorlie, Cue and Mount Magnet (Long, 1981). It has also crossed the sea to settle on Rottnest and Garden Islands.

6.6 Status of the Species Outside of Australia:

The origins of distribution of the Spotted Dove are Southern Asia, from north-eastern China, Taiwan, Hainan, west to India and Pakistan and south to Burma, Sri Lanka, Sumatra, the Malay Peninsula, Java, Palawan, Borneo and the lesser Sunda Islands (Long, 1981, p. 220).

The dispersal of introduced populations of the Spotted Dove varies across locations. In Fiji, populations are described as being limited to towns and villages, but excluded from native forests; whereas, in Hawaii they are widespread throughout both urban and rural areas.

In southern California, the Spotted Dove was either freed or escaped and by 1917 had established permanent populations in the wild. Population growth was exponential and the species was soon classified as common. By 1921 it had spread throughout Los Angles and by 1933 was established in urban outliers. There is some speculation that subsequent escapes or releases contributed to this range expansion. By the 1960s the range of the Spotted Dove extended into San Diego. Since then, populations have continued to increase and range expansion has continued.

In some areas where they have been introduced, the Spotted Dove is now classified a pest. For example, in the Fijian Islands they are blamed for destroying rice crops. This is unusual as they do not damage rice crops in their native range of China, where at worst, they sometimes scratch up planted seed (Long, 1981).

The origins of the Laughing Dove are cross-continental, extending from Africa to Southern Asia, taking in São Tomé Island, southern Africa, Israel, Jordan, Anatolia, the Arabian Peninsula, Afghanistan, Turkey, Iran, India, Pakistan, far north-west China, Socotra Island and Andaman Islands (1981, p. 222).

The distributions of these already widely dispersed species have expanded following their introduction into many other locations. At times, a result of deliberate acclimatisation, or alternatively due to the release or escape of captive birds, more-so the decorated Spotted Dove, than the plain plumaged Laughing Dove (Table 6.3).

The Laughing Dove, has also been a successful coloniser, especially around areas of human habitation and "in plantations a long way from buildings" (Long, 1981, p. 223). In Africa, where it originates, the species eats small seeds, corn and other crops and in some regions are not viewed favourably due to damage they cause to grain crops.

Table 6.3: Global introductions of *Streptopelia* doves
(Adapted from Long, 1981, p. 205)

The Extent of Global Introductions of *Streptopelia* Doves (Adapted from Long, 1981)			
Spotted Dove	**Date Introduced**	**Region**	**Manner/Reason**
	1835	Sulawesi, Moluccas and isles in Flores Sea, Indonesia	Deliberate (?)
	Prior to 1941	Fijian Group (Viti Levu)	Escapees
	Unknown	New Britain (Rabaul)	Unknown
	1939	New Caledonia	Unknown
	Early 19 century	New Zealand (Auckland)	Escapees
	Prior to 1900 (and recently?)	Hawaiian Islands	Deliberate
	About 1917 or 1918 or earlier	United States of America (southern California)	Escapees
	1870, 1872, 1874, 1881, 1898*, 1912	Australia (Western Australia)	Deliberate/aesthetic
	1781 or early 19thC	Mauritius	Unknown
Laughing Dove	**Date introduced**	**Region**	**Manner/Reason**
	About 1905	Principe, Gulf of Guinea	Unknown
	1898	Western Australia	Deliberate/aesthetic
	Prior to 1926	Lebanon, Turkey, Malta, southern Algeria	Unknown
	Unknown	Mafia Island (East Africa), Africa	Unknown
	Unknown	Israel, Jordan, Syria	Unknown

A recent study by Schuler *et al.* (2012) examined Panzootic pathogens transmitted by pigeons (Columbiformes). The study included the Eurasian Collared Dove (*S. decaocto*), a close relative of *S. chinensis and S. senegalensis*. The Collared Dove has widely colonised western America and is linked to outbreaks of Pigeon Paramyxovirus (PPMV) in 2009-10.

The outbreaks hinted at an emerging Panzootic with mortality events linked to the disease recorded in Montana, Arizona and Florida. The PPMV outbreaks had potential ramifications for other localities if the pathogen passed to other wild and domestic birds.

The Panzootic outbreaks of PPMV in pigeons were first identified in Iran in 1978. Further outbreaks were reported in Eastern Europe in relation to feral pigeons; pigeons and Eurasian Collared Dove in Italy; and racing and feral pigeons in Western Europe. The potential risk to domestic birds was first recognised in 1984 when an outbreak in pigeons caused by faecal contamination by infected pigeons, was linked to 22 cases of Newcastle disease in chickens in the United Kingdom.

Similarly, Canada had an outbreak of PPMV in commercial layer chickens which was also linked to feed contaminated by faeces of PPMV-infected pigeons. Infected pigeons were also identified in Nova Scotia in 2001 and infections of PPMV in poultry were recorded in France, 2010 and Sweden, 2011. The outbreaks were caused by wild birds entering poultry houses. The virus has also reached Australia, with PPMV first detected in 2011 in racing and show pigeons.

Whilst transmission events are rare, a single spill-over occurrence could result in catastrophic consequences for native species. To date, the virus has transcended ecological barriers such as geographic separation, which highlights the importance of developing strategies to prevent between-species transmission, if eradication of the pathogen fails. There is little doubt that anthropogenic factors assisted these outbreaks, specifically through the introduction of exotic species, of feeding stations (e.g., birdfeeders), and the presence of feral species.

It has been proved that non-native species disrupt and threaten natural ecosystems in many ways; including acting as reservoirs for disease. Whilst PPMV spill-over to native species has not yet occurred in America, Europe or Australia, it would be difficult to manage should it happen (Schuler *et al.*, 2012). It is essential to view exotic disease risks to wildlife seriously, and prohibit any such introductions.

There is nothing to suggest that wild populations of the Spotted Dove and the Laughing Dove within the study area harbour this harmful pathogen. However, scenarios concerning Collared Dove in America and Europe offer a reminder that introduced species can pose a potential threat to native species. The Collared Dove though has no permanent populations in Australia. A few were sighted in Sydney in 1946, and again in suburban Perth in 1975 at Wattle Grove. The colony of about 15 birds was immediately destroyed and there have only been isolated sightings since.

Meanwhile, a report by a local wildlife rehabilitation group based in the Darling Ranges, lists doves, including the introduced *Streptopelia* species, as carriers of Avian Pox virus. The blight causes wart-like growths on the skin around the eyes, beak, legs and feet. The virus can survive for long periods of time in scabs and litter and poses a threat to avian health in the region (Kanyana Wildlife, 2010).

6.7 Data Analysis:

The following summaries follow the same format as prescribed earlier. Discussion is based on the presentation of spatial and temporal data prepared for the present study, presented as a map series: Era A (1898 – 1953), *Introduction, Death or Captivity*; Era B (1954-1980), *Establish or Fail*; Era C (1981-2007), *Spread or Remain Local*; All Eras (1898-2007); Chronology of Spread; and *Spatial Statistics*, all which examine changes in dispersal over time in relation to landscape and climate features. Spatial autocorrelation analyses examine the dispersion of the species i.e. patterns of spread within the distributions. The accompanying discussion is to contextualise and 'tell the story' of the species colonisation of the study area

Whilst every effort was made to ensure the integrity of the data, and they are as true and correct as possible, a reminder that it is subject to limitations is proffered. The analyses to follow are based upon the sightings recorded and are cannot claim to be a definitive summary.

6.7.1 Transport:

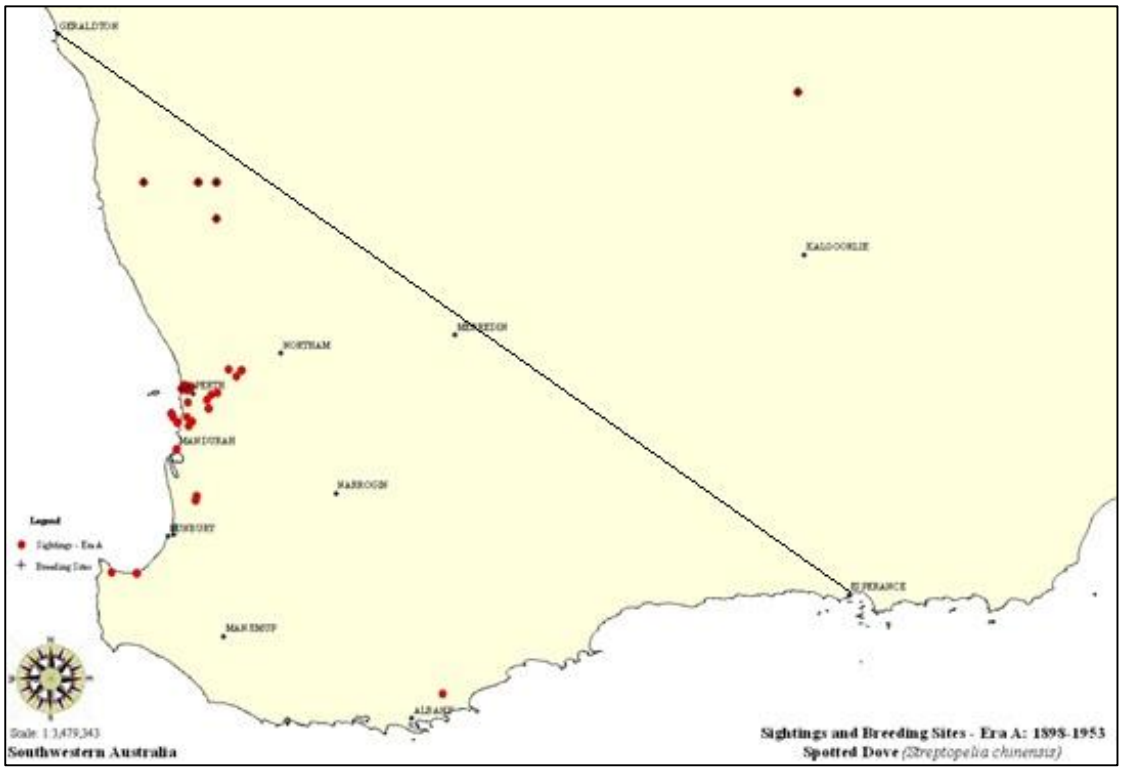
The stories of the Spotted Dove and the Laughing Dove commences *circa* 1898-99. The release of "Indian cinnamon doves and two 'kinds' of bar-shouldered dove, thirty-five in all" (Long, 1988, p. 18), was arranged by the Western Australian Acclimatisation Committee, and is so reported in their Annual Report 1898-99. The release of the birds, reputedly sourced from Melbourne (Saunders & de Rebeira, 1985), was overseen by the inaugural Director of the Perth Zoological Gardens, Ernest Le Souëf , in October 1898 to coincide with the opening of the zoo.

Other than metropolitan releases, the species were also freed in country areas up until the 1920s (Blakers *et al.*, 1984; Long, 1972). Rural liberation sites include Northam, Yatheroo and Dardanup (Long, 1988). There are no records to substantiate claims of birds being released from Kings Park. It seems the release of both the *Streptopelia* species was for purely aesthetic reasons, as is evident in a letter from Le Souëf to D.L. Serventy, dated April 27, 1936:

> All my life I had been used to hearing them in the early mornings and I missed their note very much. In my opinion they are harmless, only eating a little seed and I have never seen a dove affected by stickfast, If people objected to their eating fowl feed or garden seeds we always gave permission to shoot them, or otherwise destroy them (Sedgwick, 1958a, p. 93)

The spread of the two *Streptopelia* species is starkly contrasted. It is this marked contrast which forms the basis for the following discussion.

6.7.2 Era A: 1898 – 1953: Introduction, Death or Captivity:



Map 6.1: Dispersal of Spotted Dove, Era A: 1898 – 1953
(Includes Breeding)

Sightings of the Spotted Dove in Era A (•) 1898-1953, *Introduction, Death or Captivity* phase (Map 6.1), remain closely aligned with the release sites at the Zoological Gardens, South Perth; and rural sites at Yatheroo, Dardanup, Northam and possibly Katanning (Sedgwick, 1958b). By 1912, the species had spread across the metropolitan area, with range expansion continuing up until the mid-1930s. However, it "proved less venturesome" (Warham, 1957, p. 9) than the Laughing Dove and it remained concentrated in area between Perth and Mandurah.

Sightings outside of the metropolitan area are probably linked to liberations in those vicinities, rather than range expansion by urban populations into rural areas. However, the trend of movement towards Northam may be an indicator of the species following the rail and road networks that service the town. The sightings inland north-east of Perth are close to Moora, near Yatheroo; those to the north of Bunbury are near Dardanup, reputed rural release sites.

Although the species did not disperse widely across land, it did cross the sea to settle both Garden Island and Rottnest Island. The records of D.L. Serventy (1938) list several present on Garden Island in May 1937; and again in January 1939. It settled a little later on Rottnest Island with the earliest records indicating their arrival in 1938 (Sedgwick, 1958b; Serventy, 1938; Storr, 1965). By the early 1950s the species was termed "a moderately common resident" (Saunders & de Rebeira, 1985, p. 65). It had mainly settled the heavily wooded east side of the island. An extensive fire which later destroyed most of the woodland habitat resulted in a substantial decline in their numbers, particularly in the fire affected areas.

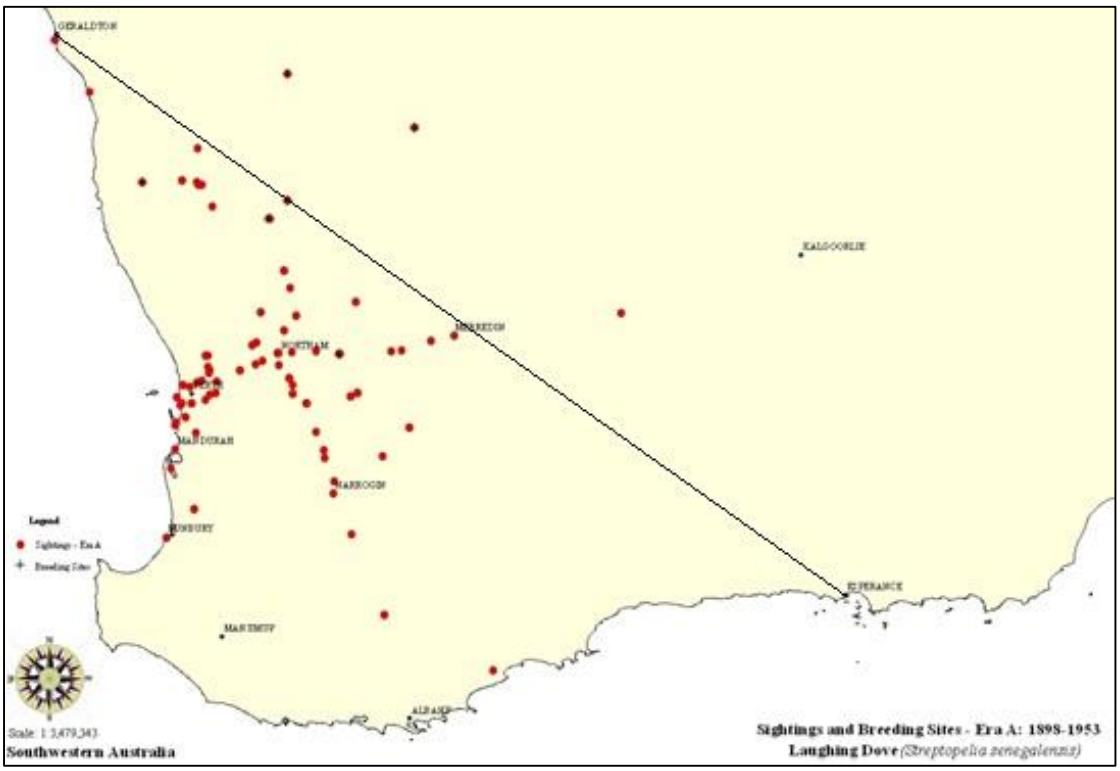
The summary below (Table 6.4) combines records from the Present Study with those included in Sedgwick (1958b). If a location is repeated it represents a conflict in the date of sighting between this study and the Sedgwick records.

The summary shows that within a few decades following liberation the Spotted Dove had colonised across the metropolitan area, along the coast and further inland. It was also in some country areas, with the most distant localities listed as Winchester to the north; White Lake, near Albany to the south; and Wooroloo to the east.

As stated previously, sightings in rural areas may be a result of liberations in the vicinity rather than range expansion by urban populations. For here, as in other Australian states, the species maintained highly localised urban populations close to human settlement and avoided both wooded and cultivated rural localities. Only time will tell if those sighted in rural areas retained permanent self-sustaining populations.

Table 6.4: Spotted Dove: Era A: Summary of Sightings – Urban and Rural
(Source: Derived from the Present Study and Sedgwick, 1958b)

Spotted Dove (*Streptopelia chinensis*) **Era A Sightings: 1898 – 1953- Urban and Rural** * Denotes records from Sedgwick			
Year	**Location**	**Year**	**Location**
1916	Claremont	*circa 1948*	Busselton*
1921	Perth	1948	Bickley
1928	Kings Park	1948	Yarloop
1929	Busselton	1951	Bibra Lake
1929	Cookernup	1951	Bickley Reservoir*
1937	Garden Island	1951	Chidlow
1937	Rottnest Island	1951	Cookernup*
1937	White Lake (near Albany)	1951	Wooroloo
1938	Baldivis	1952	Floreat
1938	Rockingham	1953	Crawley
1938	Rockingham (East)*	1953	Gidgegannup
1938	Rottnest Island*	1953	Gosnells
1938	Swanbourne	1953	Kwinana
1938	Wellard	1953	Millenden
1939	Yunderup	1953	Quindalup
1944	Mandurah	1953	Rockingham*
1945	Armadale	*circa 1953*	Katanning
1946	Winchester	1955	Bunbury



Map 6.2: Dispersal of Laughing Dove, Era A: 1898 – 1953
(Includes Breeding)

The records for Era A (•) 1898-1953, *Introduction, Death or Captivity* phase for Laughing Dove (Map 6.2), show it was "by far the more enterprising [sic]" (Sedgwick, 1958a, p. 93) of the two *Streptopelia* species. It spread rapidly and widely, and by 1902-03 was present throughout the metropolitan area and had "penetrated to some country towns". (Serventy, 1948, p. 286). As with the Spotted Dove, other than liberations at the zoo, the species was "continually despatched to applicants in various country districts" up until the 1920s (Long, 1988, p. 7). It reputedly thrived in locations where there were pines for nesting.

The Laughing Dove also colonised offshore, in fact, several years earlier than the Spotted Dove. The first of the species recorded at Garden Island in 1920 were thought to have been blown there by strong easterly winds. However, over time, it did not "become established so far as it has on Rottnest" (Serventy, 1938 p. 268).

The presence of the Laughing Dove on Rottnest is first mentioned by Kilpatrick, who wrote that the island hosted several introduced species, including "…Peacocks, Pheasants and the Turtle Dove, all of which have become very common" (Kilpatrick, 1932, p. 31). Later, Serventy wrote of the Senegal Turtle-Dove:

> …that Rottnest was free of them until about the summer of 1930-31, since when the species is firmly established in the eastern (settled) portion of the island (Serventy, 1938 p. 266).

As on the mainland, offshore the Laughing Dove was more widespread and numerous than the Spotted Dove. Its populations occupied the whole east side of the island near lakes lined by heath thickets as well as wooded areas in the middle of the island. Whilst the species is not the cause of the disappearance of the only native pigeon on the island, the Brush Bronzewing (*Phaps elegans*), which was already extinct prior to its arrival; the lack of an ecological competitor is thought to have aided its colonisation of the island (Serventy, 1938).

In the metropolitan area, the Laughing Dove had settled outlying suburbs such as Rockingham and Bickley by 1930-31. In the country, B. V. Teague reports that by 1947 it had colonised Northam, York Beverley, Brookton, Pingelly and Narrogin. Its colonisation and rapid range expansion is less surprising perhaps when considered in the context of it having inhabited towns and villages for centuries in its native Africa and southern Asia, that although "naturally a bird of arid areas…is now typically a bird of human habitations" (Goodwin, 1978, p. 74).

The species continued to spread widely into the late 1950s and continued to push north, east and south, establishing in Geraldton, Wongan Hills, Northam, Muresk, Toodyay, Beverley and Harvey. By which time it had established a far greater presence "in more country towns than *chinensis*" (Tarr, 1950, p. 191) which remained concentrated in the metropolitan area.

As with Spotted Dove, sightings records from the Present Study are combined with those from Sedgwick (1958b) (Table 6.5) as a means of augmenting the earlier record (similarly, if a location is repeated it is due to a conflict in the date of sighting between the Present Study and that recorded by Sedgwick). Comparatively, there are many more listings recorded for Era A, 1898 – 1953, for the Laughing Dove, than for Spotted Dove. It not only settled more locations, but the species dispersed much further than the Spotted Dove.

There is well-defined spread by the Laughing Dove into Wheatbelt areas despite the harshness of the terrain. Its dispersal appears to parallel transport routes, i.e. roads and rail networks that service the region, probably sustained by the supply of grain spilled during transport (Plate 6.13).

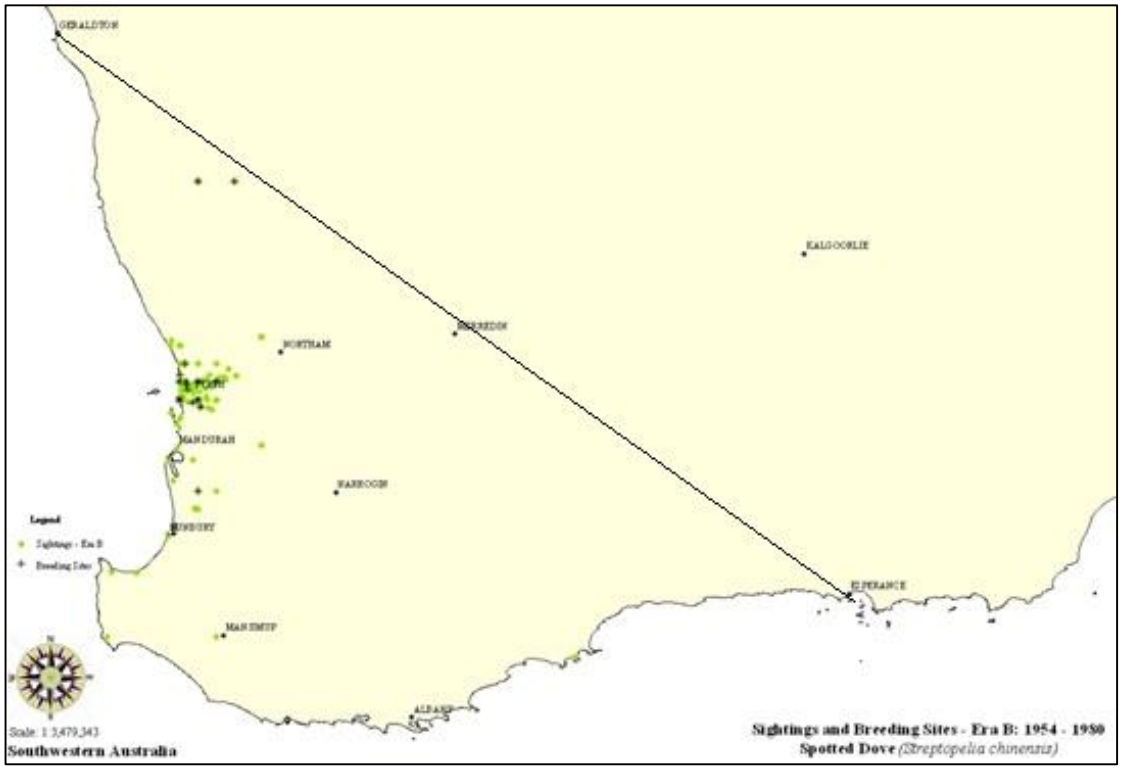
Plate 6.13: Bagged wheat at rail siding
(Pitts, *Circa* 1915)

Table 6.5: Laughing Dove: Era A: Summary of Sightings – Urban and Rural
(Source: Derived from the Present Study and Sedgwick, 1958b)

Laughing Dove (*Streptopelia senegalensis*) Era A Sightings: 1898 – 1953 – Urban and Rural *Denotes records from Sedgwick					
Year	**Location**	**Year**	**Location**	**Year**	**Location**
1924	Perth	1951	Bolgart	1953	Bickley Resevoir
1926	Northam	1951	Bullsbrook	1953	Blackboy Hill
1933	Northam	1951	Chidlow	1953	Bunbury
1938	Spearwood	1951	Goomalling	1953	Caroling Rocks
1939	Bolgart	1951	Jennacubbine	1953	Coogee
1940	Rockingham	1951	Kellerberrin	1953	Corrigin
1941	Wongan Hills	1951	Upper Swan	1953	Floreat Park
1943	Geraldton	1951	Wooroloo	1953	Greenhills
1944	Dongara	1952	Bassendean	1953	Herne Hill
1944	Geraldton	1952	Bayswater	1953	Hines Hill
1945	Cunderdin	1952	Beacon	1953	Jandakot
1945	Dangin	1952	Bickley	1953	Kwinana
1945	Quairading	1952	Cuballing	1953	Meckering
1946	Toodyay	1952	Cunderdin	1953	Millenden
1946	Winchester	1952	Floreat	1953	Parkerville
1947	Beverley	1952	Gilgering	1953	Pearce
1947	Brookton	1952	Glen Forrest	1953	Qualen
1947	Narrogin	1952	Grass Valley	1953	Safety Bay
1947	Pingelly	1952	Guildford	1953	Upper Swan
1947	Safety Bay	1952	Jandakot	1953	Wagin
1947	York	1952	Karping	1953	Watheroo
1948	Garden Island	1952	Merredin	1953	Yealering
1949	Tambellup	1952	Woolundra	1930-31	Rottnest Island
1949	Wyalkatchem	1952	York	*circa* 1948	Harvey
1950	Jarrahdale	1953	Bakers Hill	*circa* 1948	Muresk

Contrarily, the species avoided the cooler, moister; more intensely settled and forested areas to the south-west. Both these aspects particular to the distribution of the species are investigated (under separate headings) later in the chapter. Discussion now moves to an examination of the next phase of spread.

6.7.3 Era B: 1954 – 1980: Establish, or Fail:



Map 6.3: Dispersal of Spotted Dove, Era B: 1954 – 1980
(Includes Breeding)

In the second phase of the invasion, Era B (•) 1954-1980, *Establish or Fail* phase (Map 6.3), there are several developments that occur in the dispersal of the Spotted Dove. The most notable relate to the increased presence of the species in urban areas; and the limited movement of the species into rural areas (Table 6.6).

During Era A, 1898-1953, the distribution of the Spotted Dove across the metropolitan area was intermittent and widely spaced. In Era B, *Establish or Fail* phase, sightings in urban areas intensify and became concentrated. The species pressed eastward into suburbs wherein it had not been previously sighted including East Perth (1955), Highgate and Mount Lawley (1976); and to the south-east at Bedfordale (1954), Maddington (1960) and Forrestdale (1972).

Although the species had breached the Darling Scarp in Era A to settle in the urban-rural fringe in localities such as Gidgegannup and Chidlow, in Era B the species established a presence in the foothills at Forrestfield (1967) and Maida Vale (1976) as well as less distant hills suburbs such as Gooseberry Hill and Mundaring (1957); Middle Swan and Stoneville (1958); and Hovea and Parkerville (1959).

In Era A, there were very few sightings of the species in suburbs north and west of the Swan River. By Era B it was recorded north of the city at Wanneroo (1971), Lake Joondalup (1973) and Yanchep (Loch McNess) (1978). To the west, it was recorded at Wembley (1964), West Perth (1969), Churchlands, Cottesloe, Dalkeith, Nedlands, Peppermint Grove and Shenton Park (1976).

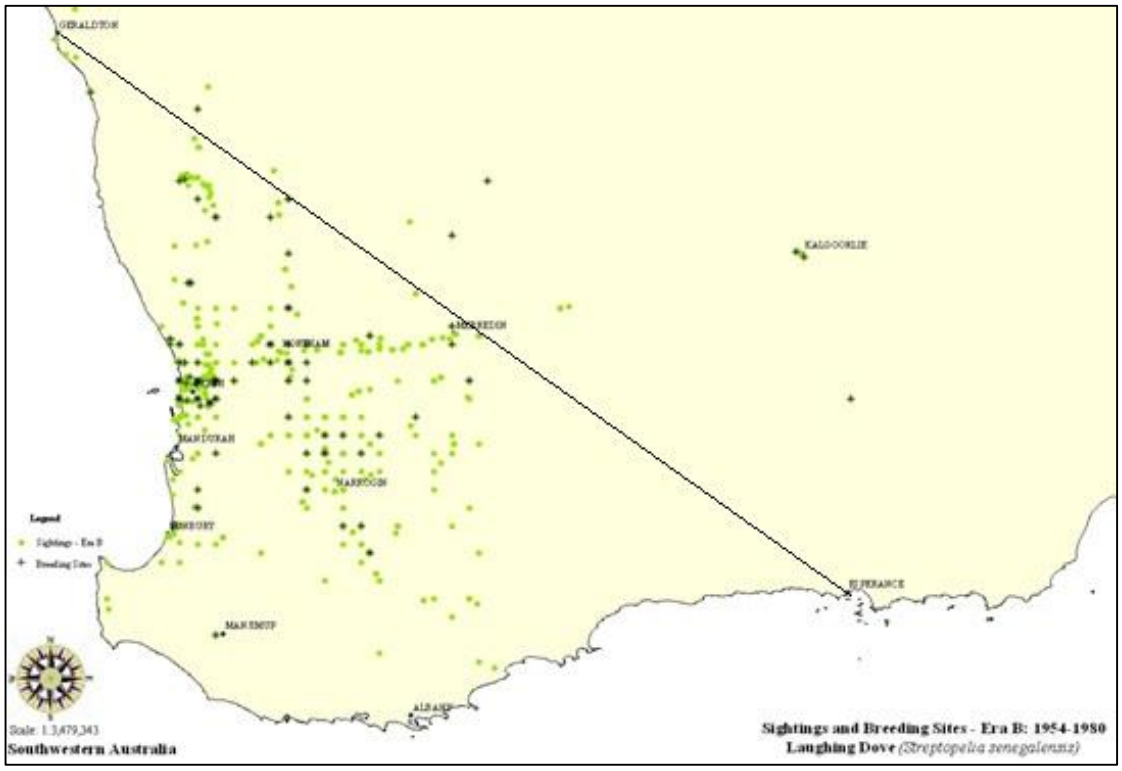
Table 6.6: Spotted Dove: Era B: Summary of Sightings – Urban and Rural
(Derived from the Present Study)

Spotted Dove (*Streptopelia chinensis*) Era B Sightings: 1954 – 1980: - Urban and Rural					
Year	**Location**	**Year**	**Location**	**Year**	**Location**
1954	Bedfordale	1959	Guildford	1976	Dalkeith
1955	East Perth	1959	Hovea	1976	Highgate
1955	Lake Claremont	1959	Parkerville	1976	Maida Vale
1955	Safety Bay	1960	Maddington	1976	Manning
1956	Harvey	1961	Wanneroo	1976	Midland
1956	Pinjarra	1964	Wembley	1976	Mount Lawley
1957	Bentley	1967	Forrestfield	1976	Nedlands
1957	Gooseberry Hill	1969	West Perth	1976	Palmyra
1957	Mundaring	1971	Lake Clifton	1976	Peppermint Grove
1958	Dawesville	1972	Forrestdale	1976	Shenton Park
1958	Fremantle	1973	Lake Joondalup	1977	Herdsman Lake
1958	Middle Swan	1975	South Perth	1978	Bayswater
1958	Stoneville	1976	Churchlands	1978	Jandakot
1958	Victoria Park	1976	Cottesloe	1978	Yanchep

However, overall the species maintained localised urban populations with sightings mainly along a north-south axis extending approximately 60km north to Yanchep (Loch McNess) and 70km south to Mandurah. The species spread inland as far as Chidlow, about 50km east, an area much more heavily wooded than along the coast.

It was well represented in coastal localities to the south through to Mandurah and beyond, with sightings in Safety Bay (1955) Dawesville (1958) and Lake Clifton (1971). In Mandurah, the presence of the species is recalled by a visitor to the area in 1968 who remembers seeing “five Indian Doves (*Streptopelia chinensis*) feeding on the sand-flat adjacent to the beach at Mandurah” (Stranger, 1969, p. 71).

In rural areas the species was sighted in the vicinity of Augusta and close to Manjimup. Unlike Era A, there were no sightings records for Albany. Sightings in the north-east, near Moora were also fewer although breeding was again recorded in the vicinity. On Rottnest the Spotted Dove population was decimated by an extensive scrub fire in 1955 (Saunders & de Rebeira, 1985).



Map 6.4: Dispersal of Laughing Dove, Era B: 1954 – 1980
(Includes Breeding)

The tale of the Laughing Dove for Era B (•) 1954-1980, *Establish or Fail* phase (Map 6.4), was markedly different to that of the Spotted Dove. Whilst its presence in urban areas intensified (Table 6.7), it is the widespread dispersal of the species into the central and southern Wheatbelt that figures most prominently (Table 6.8).

The extent of spread inland is somewhat surprising, given its highly sedentary nature. Such is evidenced by R.H. Stranger who cites numerous examples of the species returning to the capture site after having been relocated despite having "no visual knowledge of the route taken" (1961, p. 191). These include a bird relocated 27km, and another 160km to the Wheatbelt town of Meckering, that made their way back to the suburban capture site (Pers. Comm., R. H. Stranger, 26 June 2008).

As with the Spotted Dove, the presence of Laughing Dove in urban areas intensified and became more concentrated. Its spread into areas north of the Swan River was mainly inland, although there was also some range expansion north along the coast. Similarly, sightings south of the river intensified with space between records decreasing. There was also movement away from the coast. However this trend gradually reduces toward Mandurah with sightings further south becoming intermittent. In terms of urban expansion overall, the species continued to establish across the metropolitan area and up into the Darling Ranges (

Table 6.7: Laughing Dove: Era B: Summary of Sightings – Urban
(Source: Derived from the Present Study and Sedgwick, 1958b)

Laughing Dove (*Streptopelia senegalensis*) Era B Sightings: 1954 - 1980: - Urban *Denotes records from Sedgwick			
Year	**Location**	**Year**	**Location**
1954	Crawley	1959	Wanneroo
1954	Welshpool	1960	Point Peron
1955	Kelmscott	1961	Bibra Lake
1955	Armadale	1967	Forrestfield
1955	Baldivis	1969	Wembley
1955	East Perth	1972	Caversham
1955	Perth	1972	Forrestdale
1956	Greenmount	1973	Osborne Park
1956	Swan View	1974	Woodman Point
1957	Kenwick	1975	Maylands
1957	Bibra Lake*	1975	Nollamara
1958	Fremantle	1976	Balcatta
1958	Maddington	1977	Lake Joondalup
1958	Midland	1977	Ellenbrook
1958	Rivervale	1978	Burns Beach
1958	South Fremantle	1978	Yanchep
1959	Middle Swan	1980	Medina
1959	Tuart Hill		

The movement of the Laughing Dove into rural areas, as stated previously, is predominantly eastward into wheat producing districts (some localities are shown in Map 6.5), although the species also advanced northward, utilising transport routes. The sightings peter-out north of Yanchep, beyond the urban-rural fringe although they continue linearly for some time before becoming intermittent and widely spaced. The concentration of sightings in the north-east sector is situated near Yatheroo, a rural release site.

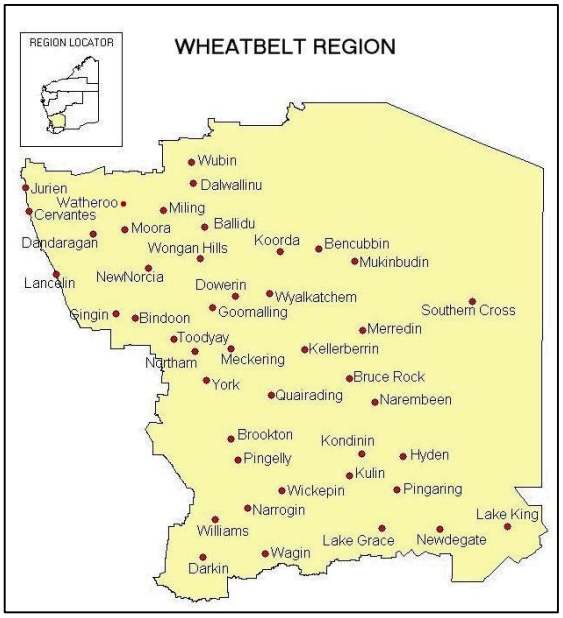
The advance of the species to the south is concentrated between Bunbury and Margaret River on the Southwest Peninsula. The area supports sizeable urban enclaves interspersed amongst landholdings cultivated for primary industries such as fruit growing (apples, pears, stone-fruit and grapes), as well as beef and dairy farming.

The spread of the Laughing Dove terminates around Donnybrook, beyond which the landscape becomes heavily wooded and supports a lower density of human population. The Laughing Dove has avoided these forested areas, as they do not provide ecological resources for feeding or breeding. In any event the species has failed to infiltrate the dense timbers and undergrowth of the sclerophyll forest.

Table 6.8: Laughing Dove: Era B: Summary of Sightings – Rural
(Source: Derived from the Present Study and Sedgwick, 1958b)

Laughing Dove (*Streptopelia senegalensis*)
Era B Sightings: 1954 - 1980: Rural
* Denotes records from Sedgwick

Year	Location	Year	Location	Year	Location
1954	Baandee	1957	Bungulla	1966	Nangeenan
1954	Doodlakine	1957	Collie	1966	Eaton
1954	Gnowangerup	1958	Busselton	1966	Serpentine
1954	Narrogin	1958	Bruce Rock	1967	Meenaar
1954	Popanyinning	1958	Muchea	1967	Narembeen
1954	Quairading	1959	Dardanup	1970	Pinjarra
1954	Wickepin	1959	Dawesville	1971	Kulin
1955	Esperance*	1959	Gingin	1973	Dumbleyung
1955	Mackies Siding*	1959	Lamington	1973	Herdsman Lake
1955	Parkeston*	1959	Walkaway	1973	Morawa
1955	Claremont	1960	Greenough	1973	Nabawa
1955	Claremont, Lake	1960	Katanning	1974	Kununoppin
1955	Merredin	1960	Livesey	1976	West Merredin
1955	Spencers Brook	1961	Hines Hill	1977	Bindoon
1955	Williams	1961	Konnongorring	1977	Chandala
1956	Burges Siding	1961	Pithara	1978	Carnamah
1956	East Northam	1962	Clackline	1978	Dryandra
1956	Tammin	1962	Woolundra	1978	Lake Beermullah
1957	Hines Hill*	1963	Dalwallinu	1978	Dunsborough
1957	Katanning*	1964	Dandaragan	1978	Regans Ford
1957	Moora*	1964	Goomalling	1979	Brookton
1965	Moora	1966	Kondinin	1979	Buntine



Map 6.5: Wheatbelt Region, Western Australia
(Government Electronic Marketplace, 2013)

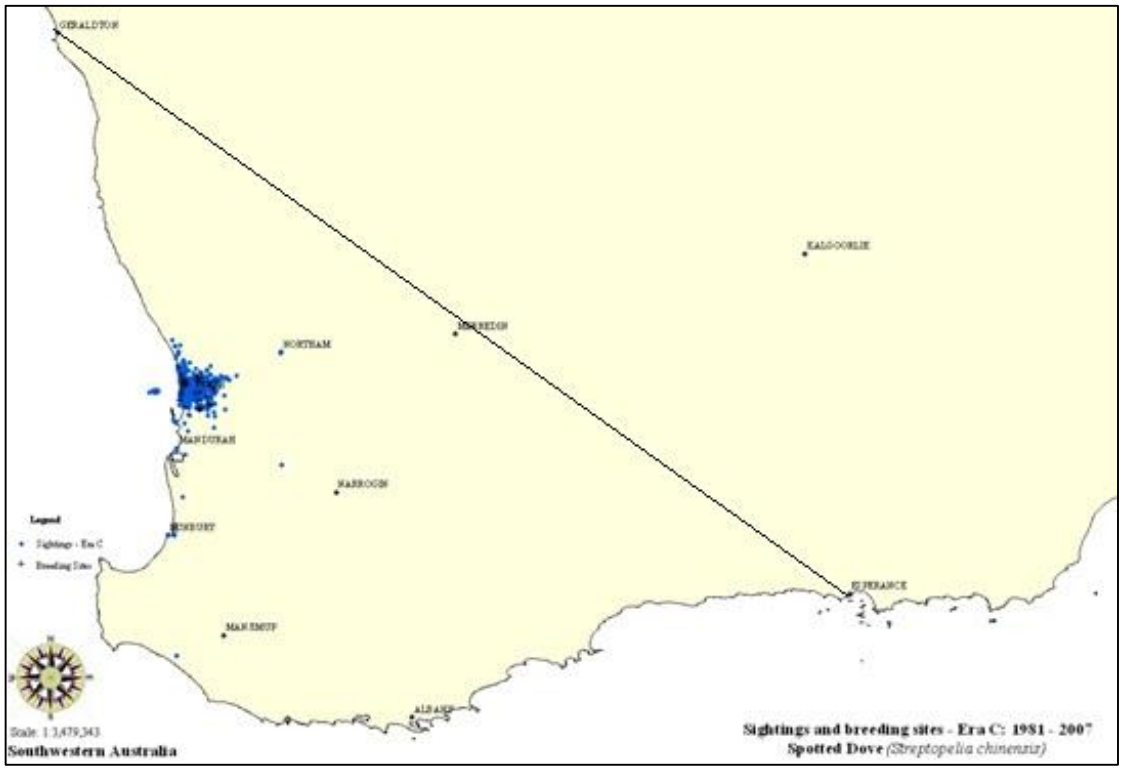
The few sightings of the species east of Albany are probably a result of stepping-stone settlement. The majority of sightings though follow the road and rail routes that traverse the Great Southern region within the southern Wheatbelt.

Overall, throughout Era B the Laughing Dove continued to spread widely throughout inland rural areas despite the conditions becoming drier as it left the coast. The landscape was heavily modified and sparsely vegetated (Plate 6.14). Throughout the study area its dispersal out-distances Spotted Dove, and the sightings are more prolific. By the close of the era the Laughing Dove has shown superior adaptability to the environmental conditions than the Spotted Dove.

As with Era A, the same can be said for its presence offshore on Rottnest Island, where it has settled the entire island and outnumbers the Spotted (Indian) Dove in just about every island location (Storr, Saunders & de Rebeira, 1985; 1965).

Plate 6.14: Typical 'Wheatbelt' **habitat**
(View from Kokerbin Rock, near Wickepin)
(Harrison, 2010)

6.7.4 Era C: 1981 – 2007: Spread, or Remain Local:



Map 6.6: Dispersal of Spotted Dove, Era C: 1981 – 2007
(Includes Breeding)

By Era C (•) 1981-2007, *Spread or Remain Local* phase (Map 6.6), there are very few sightings of the Spotted Dove in rural areas and it is evident the species can only sustain a localised metropolitan distribution (Table 6.9).

Sightings are concentrated in the metropolitan area where its presence continued to build as it spread into unoccupied territories. On Rottnest Island they now occur across the island but remain concentrated on its east-side (Saunders & de Rebeira, 1985).

The Spotted Dove was sighted in the eastern suburbs of Maylands (1982), Ascot and Redcliffe (1994), Burswood (1995) and Woodbridge (1999). It also has a presence in the hills suburbs of Darlington (1981), Helena Valley and Kalamunda. To the north it was sighted in North Beach (1982), Joondalup and Yanchep (1988), Jandabup (1992), Whitfords (1995) and Neerabup (1996).

South of the river the species had also spread into Munster (1983), North Lake and Perron (1988), Winthrop (1989), Yangebup (1990), Booragoon (1994), Beeliar (1995) and Coogee (2002). It also settled the riverside suburbs of Alfred Cove (1982), Mount Pleasant (1990), Shelly (1998), Salter Point (1999) and Wilson (2002). To the south-east new sightings include the localities of Kelmscott (1982), Jarrahdale (1987), Martin (1995) and Wungong (2002).

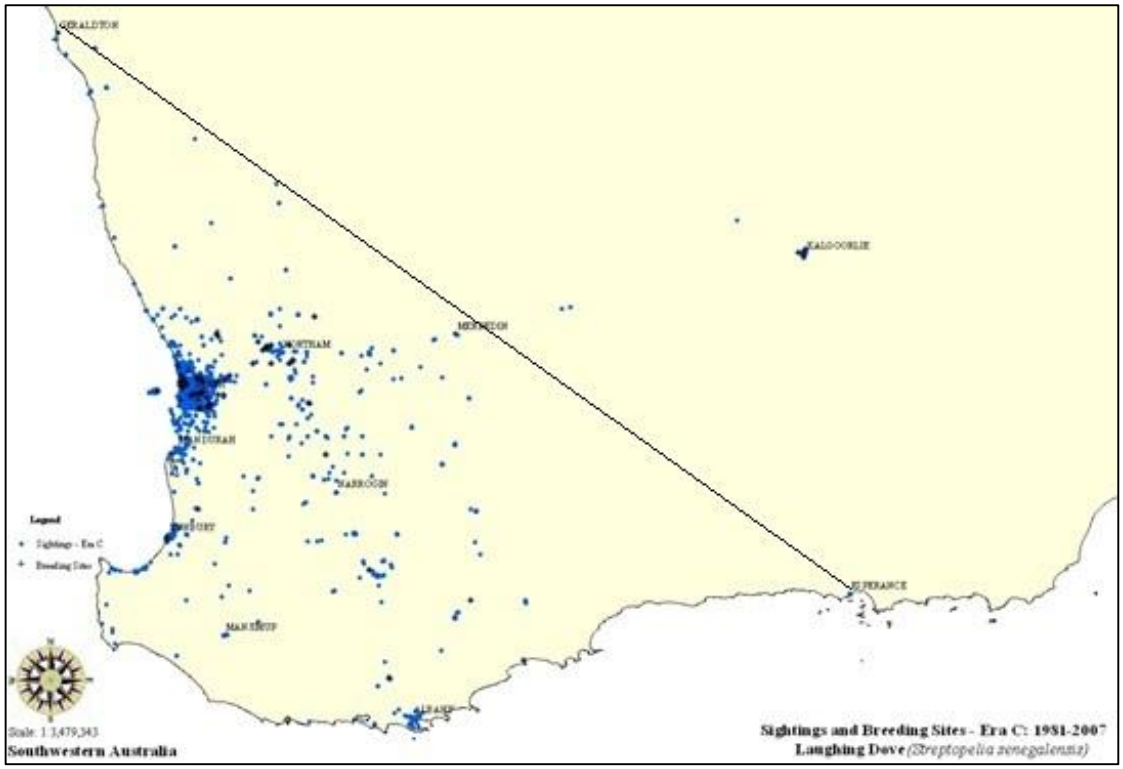
Table 6.9: Spotted Dove: Era C: Summary of Sightings
(Source: The Present Study)

Spotted Dove (*Streptopelia chinensis*) Era C Sightings: 1981 - 2007: Urban and Rural					
Year	**Location**	**Year**	**Location**	**Year**	**Location**
1981	Darlington	1989	Winthrop	1998	Karnup
1981	Kelmscott	1990	Mt Pleasant	1998	Shelley
1982	Alfred Cove	1990	Yangebup	1999	Salter Point
1982	Maylands	1991	Yokine	1999	Woodbridge
1982	North Beach	1992	Jandabup	2000	Woodlands
1983	Munster	1994	Ascot	2001	Ashfield
1984	Eaton	1994	Booragoon	2001	Banjup
1987	Helena Valley	1994	Carine	2001	Martin
1987	Jarrahdale	1994	Gwelup	2001	Riverton
1987	Kalamunda	1994	Jolimont	2002	Bicton
1988	Cannington	1994	Redcliffe	2002	Coogee
1988	Joondalup	1995	Beeliar	2002	Langford
1988	Leederville	1995	Burswood	2002	Wilson
1988	North Lake	1995	Whitfords	2002	Wungong
1988	Peron	1996	Neerabup	2006	Windy Harbour*
1988	Yanchep	1996	Whiteman		
1989	Glendalough	1997	Kingsley		

Sightings of the Spotted Dove in country areas include the localities of Eaton, Windy Gully, and Northam, as well as in the vicinities of Boddington and Harvey. However these are most probably remnant populations and whilst the species is maintaining a presence is not increasing in number in these areas. Each of these rural localities, other than Windy Gully on the south-west corner, supports sizeable areas of urban development that is the preferred habitat of the species.

In Western Australia, it appears the distribution of the species has come to mirror its distribution in the eastern states, with an occasional foray into cultivated regions, but with its stronghold in urban habitats, replete with “gardens and parks with many large, thickly-foliaged trees” (Goodwin, 1978, p. 118) (Plate 6.15).

Plate 6.15: Spotted Dove, on suburban rooftop
Note stronghold in urban habitats
(Kopp, 2012)



Map 6.7: Dispersal of Laughing Dove, Era C: 1981 – 2007
(Includes Breeding)

In Era C (•) 1981-2007, *Spread or Remain Local* phase (Map 6.7), a similar scenario to that of Era B, 1954-1980, is again presented for the Laughing Dove. Its presence has intensified in urban areas and it remains widespread in rural areas. However, overall its spread throughout the Central and Southern Wheatbelt has reduced marginally. The probably reasons for this range contraction are discussed later in the chapter.

In the metropolitan area the presence of the species intensified and become concentrated as it spread into previously unoccupied territories (Table 6.10). Along the coast it was sighted in Cottesloe (1984) then spread up to Karrinyup (1982), Eglinton (1985), North Beach and Whitfords (1990), Neerabup (1993), Hillarys (1996) and Trigg (1997). It also settled localities parallel to the northern coastline including Joondalup (1988), Gwelup (1990), Jandabup (1992), and Gnangara (1994).

To the south, the species was sighted at Beeliar (1986), Yangebup (1987), Alfred Cove (1988), Mount Pleasant and Winthrop (1990), North Lake (1992), Booragoon (1993), Cockburn and Cooloongup (1994), Wellard (1995), Karnup (1998) to as far as Mandurah (1991). To the south-east it was sighted at Bedfordale and Wungong (1988), Cannington (1998) and Martin (2001). It was also sighted in the hills at Roleystone (1986), Helena Valley and Kalamunda (1987).

On Rottnest Island, it has become the more abundant of the two introduced *Streptopelia*, and is now approximately four times more common than the Spotted Dove. Like the Spotted Dove it also favours the east side of the island. The diet of the island population has been described as similar to that of mainland birds, consisting mainly of "seed, food placed out for poultry and bread crumbs"(Saunders & de Rebeira, 1985, p. 66).

Table 6.10: Laughing Dove: Era C: Summary of Sightings - Urban
(Source: The Present Study)

Laughing Dove (*Streptopelia senegalensis*) Era C Sightings: 1981 - 2007: Urban					
Year	**Location**	**Year**	**Location**	**Year**	**Location**
1982	Karrinyup	1990	Kingsley	1997	Warwick
1984	Applecross	1990	Mount Pleasant	1998	Karnup
1984	Cottesloe	1990	North Beach	1998	Shelley
1984	Leederville	1990	Whitfords	1999	Ascot
1984	Willetton	1990	Winthrop	1999	Salter Point
1985	Eglinton	1991	Mandurah	2001	Ardross
1986	Beeliar (Thomsons Lake)	1991	Yokine	2001	Ascot
1986	Roleystone (Stony Brook)	1992	Jandabup	2001	Ashfield
1987	Helena Valley	1992	North Lake	2001	Bicton
1987	Kalamunda	1993	Booragoon	2001	Martin
1987	Munster (Woodman Spit)	1993	Neerabup	2001	Langford
1987	Yangebup	1993	Redcliffe (Perth Airport)	2001	Riverton
1988	Alfred Cove	1994	Cockburn	2001	Wilson
1988	Ascot	1994	Cooloongup	2002	Perth (Heirisson Island)
1988	Bedfordale	1994	Gnangara	2002	South Lake
1988	Cannington	1994	Jolimont	2003	Henderson
1988	Joondalup	1994	Whiteman	2003	Shenton Park
1988	Wungong	1994	Woodlands	2004	Manning
1989	Belmont	1995	Burswood	2005	Kardinya
1989	Carine	1995	Wellard	2005	Leeming
1989	West Perth	1996	Hillarys	2005	Mundaring
1990	Gwelup	1997	Trigg	2006	Waterford

In rural areas, other than a range contraction in the Central and Southern Wheatbelt, sightings in the north-east on the periphery of grain growing districts have also reduced. Around farming districts the species is perceived as a pest due to its propensity to take up residence in stables, chicken coops and grain storage sheds as a means of "obtaining their feed and water" (Pers. Comm. A. Doley, 27 December 2007). Some farmers eradicate them on sight so that they cannot become established and "fist a blight" on the locality. Overall, the movement of the species into the northern districts is widespread but intermittent outside urban areas, and decreases steadily with distance from the metropolitan area.

The movement of the species in other rural areas is considerably less than that recorded for the previous eras. Nor is the spread of the species focussed in wheat producing districts, although there were listings for Woodanilling and Wubin (1994) and Boyagin (2002) and Quairading (2005) (Table 6.11).

Sightings in other country areas include coastal localities with substantial urban settlements; to the south, localities close to Bunbury include Leschenault Estuary (1998) and Australind (2001). Further south of Bunbury sightings are listed for Yunderup (1993), Albany (1995), Margaret River (1998), Mount Barker (1997), Boyup Brook and Borden (1998) and Pemberton (2006). In Albany in particular, a regional centre that has quite extended urban setting, the species has become well established.

Table 6.11: Laughing Dove: Era C: Summary of Sightings – Rural
(Source: The Present Study)

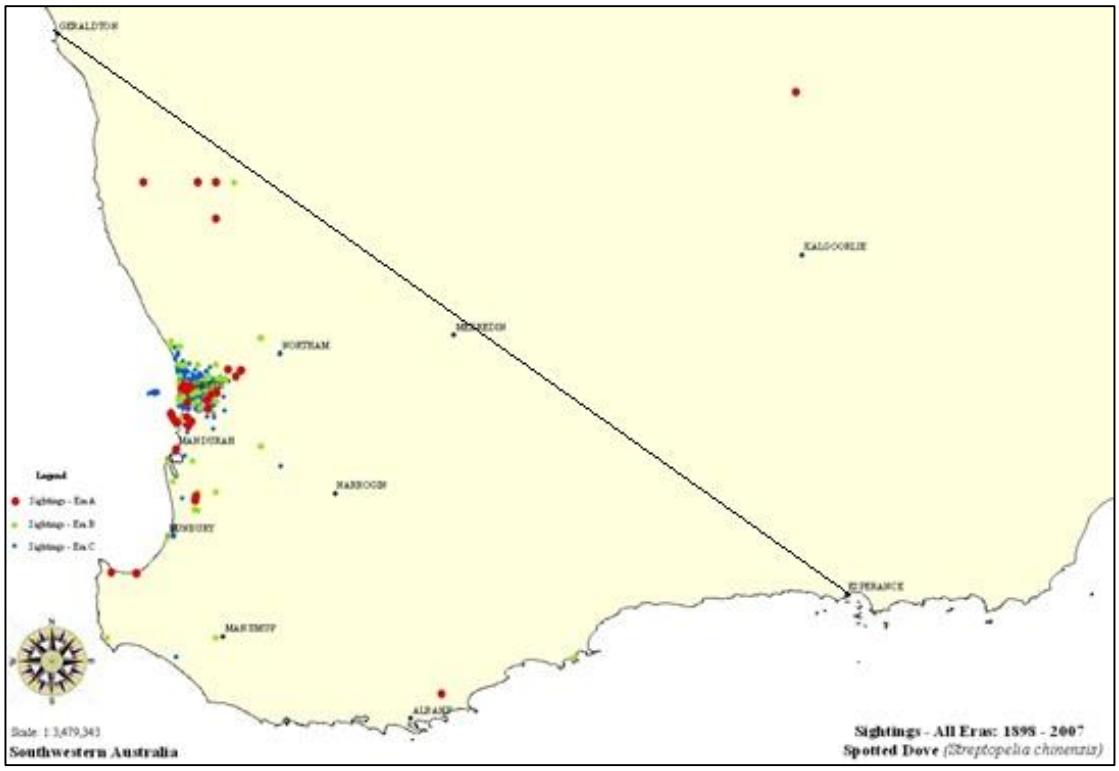
Laughing Dove (*Streptopelia senegalensis*) Era C Sightings: 1981 - 2007: Rural			
Year	**Location**	**Year**	**Location**
1989	Gidgegannup	1998	Boyup Brook
1993	Yunderup (Austin Bay)	1998	Leschenault Estuary
1994	Woodanilling	1998	Margaret River
1994	Wubin	1999	Chittering
1995	Albany	2001	Australind
1995	Waroona	2001	Port Denison
1997	Burekup	2002	Boyagin
1997	Mount Barker	2005	Quairading
1998	Borden	2006	Pemberton (Lake Wilson)

In summary, in Era C, it appears that the Laughing Dove has retained its widespread dispersal despite the range contraction throughout the wheat growing districts. The distribution shows that the species, unlike the Spotted Dove adapted more suitably to the climate and landscape conditions on a much broader scale. It has proven that it can utilise ecological resources provisioned outside of urban areas to sustain and increase its number.

In urban areas the species has become prolific and moved into all available spaces. Breeding is focussed in urban areas probably due to the accessibility and availability of nest sites and food for the young. Both can be procured from naturally occurring sources as well as the urban habitat.

Discussions relating to the spread of the species in each Era are now concluded. The combined chronological spread of the species identifying advancing waves of settlement and the contraction of distributions throughout each era follow.

6.7.5 Chronology of Dispersal: All Eras: 1898 – 2007:

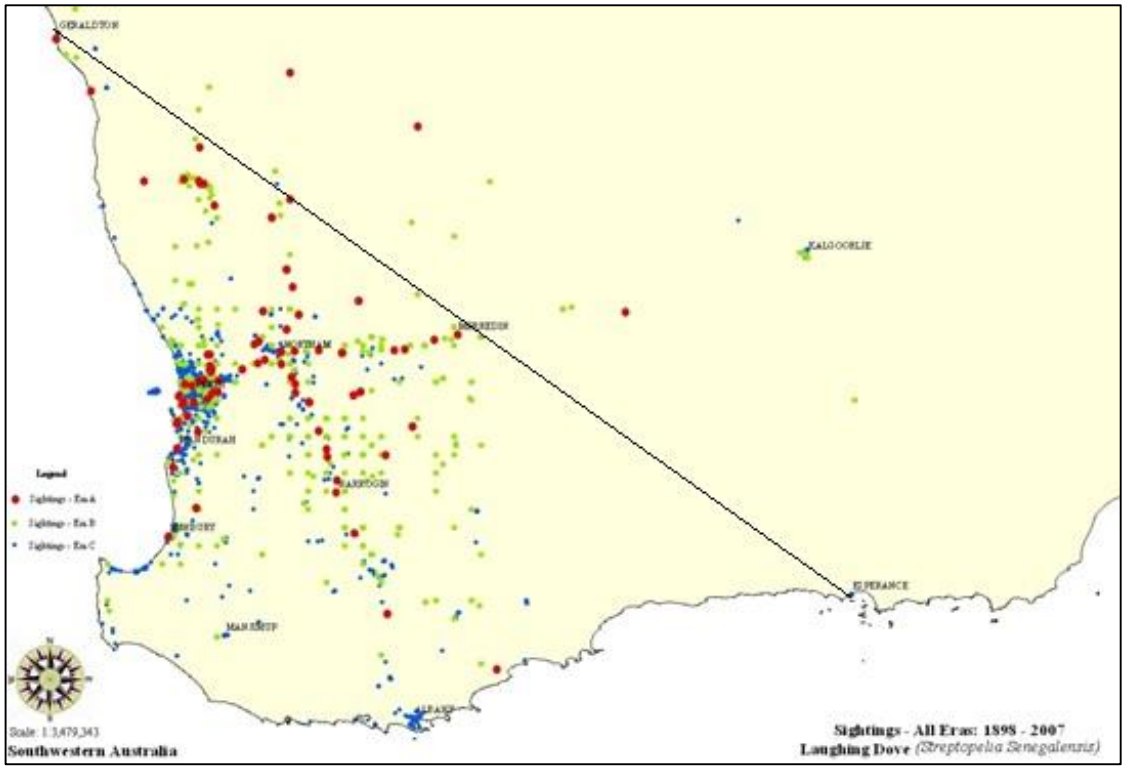


Map 6.8:Chronological Dispersal of Spotted Dove
(All Eras: 1898 – 2007) (No Breeding)

The presentation of all data chronologically is represented by: Era A (•) 1898-1953; Era B (•) 1954-1980; and Era C (•) 1981-2007 (Map 6.8). The depiction of the data indicates that the dispersal of the Spotted Dove radiates in all directions from the release site at South Perth. The extent of spread is around 60km to the west (Garden Island, 1937), 50km south (Rockingham, 1938), 45km north-east (Gidgegannup, 1953) and 40km south-east (Armadale, 1945). At the time these localities would have been classified as being on the urban-rural fringe.

The Era A sightings, 1898-195, situated between Perth and Geraldton are in the vicinity of Yatheroo; and those to the north of Bunbury are near Dardanup; both of which were rural release sites. The sightings on the Southwest peninsula at Quindalup and Yunderup (closest to the coast) are isolated and do not form population clusters or link linearly to sightings in successive eras.

Rather, throughout Era B, 1954-1980, the sightings in rural areas declined and by Era C, 1981 -2007, the species population was concentrated in urban areas. This suggests that the species was poorly suited to environmental conditions outside urban areas where food, water and shelter for roosting and nesting is available and abundant. The pattern of dispersal fits the generally accepted hypothesis that introduced populations of the Spotted Dove remain limited to within 100km of the city and its urban hinterland.



Map 6.9: Chronological Dispersal of Laughing Dove
(All Eras: 1898 – 2007) (No Breeding)

The presentation of all data chronologically is represented by: Era A (•) Era B (•) Era C (•) (Map 6.9). The patterns of dispersal for the Laughing Dove, when shown chronologically are noticeably different to those of the Spotted Dove. There are several contrasts: In Era A, 1898-1953, the dispersal of the former soon out-distances the latter by several hundred kilometres; also, the data for the species are clustered around or shows lineal connexion between sightings from Era A that are lacking in the dispersal patterns of the Spotted Dove.

The dispersal of the Laughing Dove follows distinct lineal trajectories to the east (Perth → Northam → Merredin), and south-east (Northam → Narrogin → Katanning). These traverse areas of dryland agriculture, mainly wheat production, and are aligned with major arterial road and rail networks that service these areas.

The Era B, 1954-1980, sightings appear to be spreading out from areas settled in Era A. However, in Era C, 1981-2007, there is a contraction of sightings to the east in the wheat producing districts. This can be linked to changes in grain processing, storage and cartage practices. It is an excellent example of how changes in agricultural practice can impact ecologically on a species: in this instance by decreasing food availability and reducing survival success. Whilst the species maintained a presence in the Wheatbelt, the sightings were fewer and more widely dispersed.

In the metropolitan area, the sightings become more concentrated and clustered throughout each passing era. The spread of the species is greatest north - south, aligned with coastal settlements and increasing coastal urban development.

The ‘stepping-stone’ spread of the species in Era A and Era B along the Great Southern rail and road networks ends at Albany in Era C. Albany is a regional port and grain is shipped from there. The clustering of sightings indicates that the species is firmly established in the locality: in the town and surrounding areas.

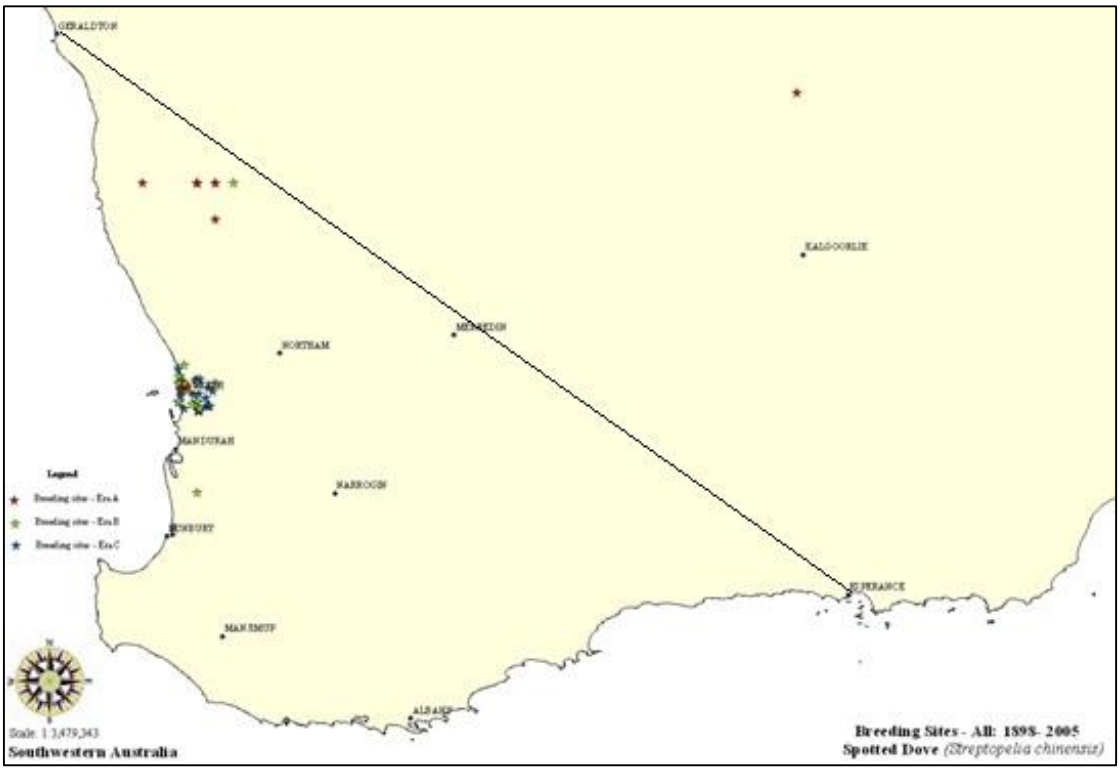
In the area between the coast and the interior, along the Great Southern transport routes, sightings are intermittent and those shown are probably linked towns, such as Donnybrook, Bridgetown and Manjimup. There is a marked absence of sightings to the east and south-east between Manjimup and Albany. The landscape is heavily wooded and is included in protected resource conservation areas.

The patterns of dispersal support the supposition of Sedgwick: that despite the propensity of the species to colonise areas close to human habitation, it has largely avoided the Southwest corner, the most densely populated region of the State other than the Perth metropolitan area. However the area is “not nearly as attractive to the birds as are the drier inland wheat producing districts” (1958a, p. 94) and it has shown a distinct preference for cleared agricultural land and for moving along road and rail routes, rather than penetrating the heavily timbered forest.

Interestingly, in Zimbabwe (formerly Rhodesia), the area from which the Laughing Dove originates, the species occupies habitats that are “curiously similar to those in Western Australia” (Serventy in Sedgwick, 1958a, p. 96). It avoids wooded areas where possible and settles close to areas of human habitations and land cleared for agriculture. Its distribution is patchy and intermittent, similar to the manner in which it has spread throughout the study area.

The colonisation and spread of the Laughing Dove throughout the study area brings to mind suggestions of Brown (1989), and presented earlier: that the most successful biological invaders are species that (a) inhabited continents prior to translocation; and (b) are matched to conditions similar to those of their country of origin; and (c) have a history of settling near humans. The areas the Laughing Dove originates from spans continents; it inhabits localities with environmental conditions similar to those that prevail in Western Australia and it has a long history of settling in close proximity to humans.

6.7.6 Breeding: All Eras: 1898 – 2007:



Map 6.10: Breeding: Spotted Dove: All Eras 1898 – 2007

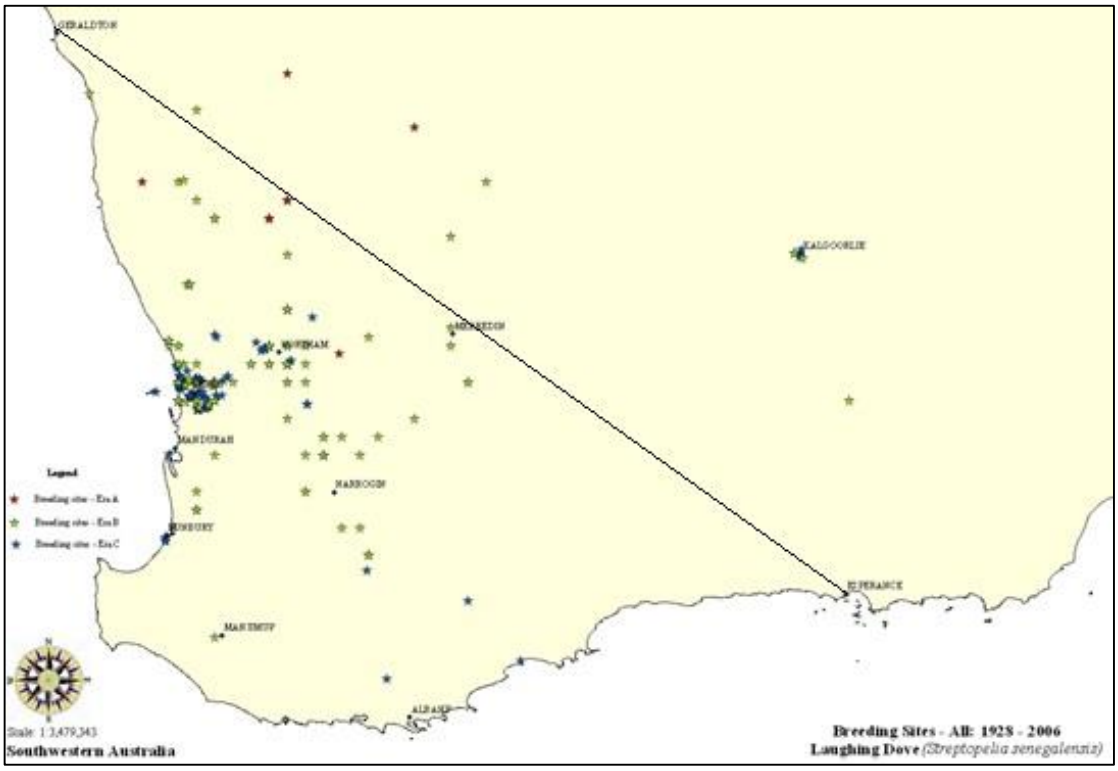
The breeding data is represented by: Era A (□) 1898-1953; Era B (□) 1954-1980; and Era C (□) 1981-2007 (Map 6.10). Breeding for the Spotted Dove is recorded in the north-eastern sector near Yatheroo/Watheroo/ Moora in Era A (in 1941 and 1951); and Era B (in 1962, 1965 and 1969). However there are no records of the species breeding in this region for Era C.

As a period of 37 years has lapsed since breeding was last recorded in the vicinity it seems that Spotted Dove did not establish widespread populations and possibly failed to sustain permanent populations in the area at all.

Whilst the lack of sightings could be attributed to limitations in data collection, each of the towns support permanent residents and have buildings and amenities that service the outlying agricultural areas. The area is also popular with tourists in the wildflower season, so there are opportunities for data collection. It seems probably that if the species existed in the area it would have been recorded.

For Era A, the breeding records (1928 and 1938) are situated around Perth city, close to the release site from the zoo in South Perth. By Era B, sightings expand beyond those for Era A to the north, south and east. However breeding records for Era C only extend beyond Era B records to the east and south-east but not the north.

Breeding by the species occurs predominantly within the metropolitan area where there are suitable and accessible nesting sites and plentiful food for the young.



Map 6.11: Breeding: Laughing Dove: All Eras 1898 – 2007

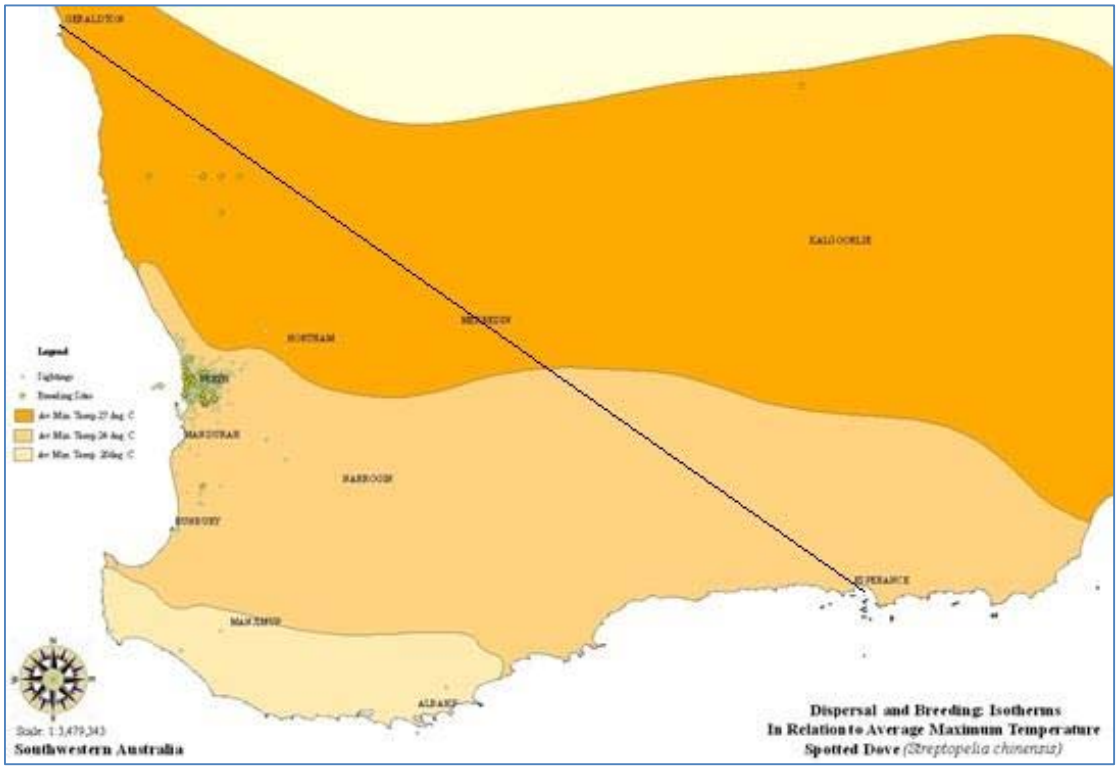
The breeding data is represented by: Era A (□) 1898-1953; Era B (□) 1954-1980; and Era C (□) 1981-2007 (Map 6.11). Just as the overall distribution of the Laughing Dove outdistances the Spotted Dove, so does the spread of its breeding pairs. The breeding data for the species in Era A extends several hundred kilometres to the north, north-west and north-east and east. However there is no breeding recorded in the metropolitan area, nor in localities to the south, south-west and south-east.

In Era B, the overall number of breeding records has increased markedly. However, it is only in areas to the east that the spread of breeding pairs extends beyond those of Era A. Also, where breeding was lacking in and around the metropolitan in Era A, it now occurs across all areas. Similarly, breeding is now occurring frequently in outlying areas to the south and south-east.

By Era C, the only extension of breeding range is to the south and south-east toward Albany and beyond. To the north, north-west and north-east there is a contraction in the breeding range. Similarly, breeding in and around the metropolitan area has not extended beyond those recorded for Era B.

On Rottnest Island the only breeding records pertain to Era C. However the species probably started breeding there from the time of its arrival in the island *circa* 1930-31 (Storr, 1965). Unlike the Spotted Dove, which says Storr, has given no hint of local reproduction occurring; nor were any breeding records for this species on the island for the present study.

6.7.7 Dispersal in Relation to Average Maximum Temperature:



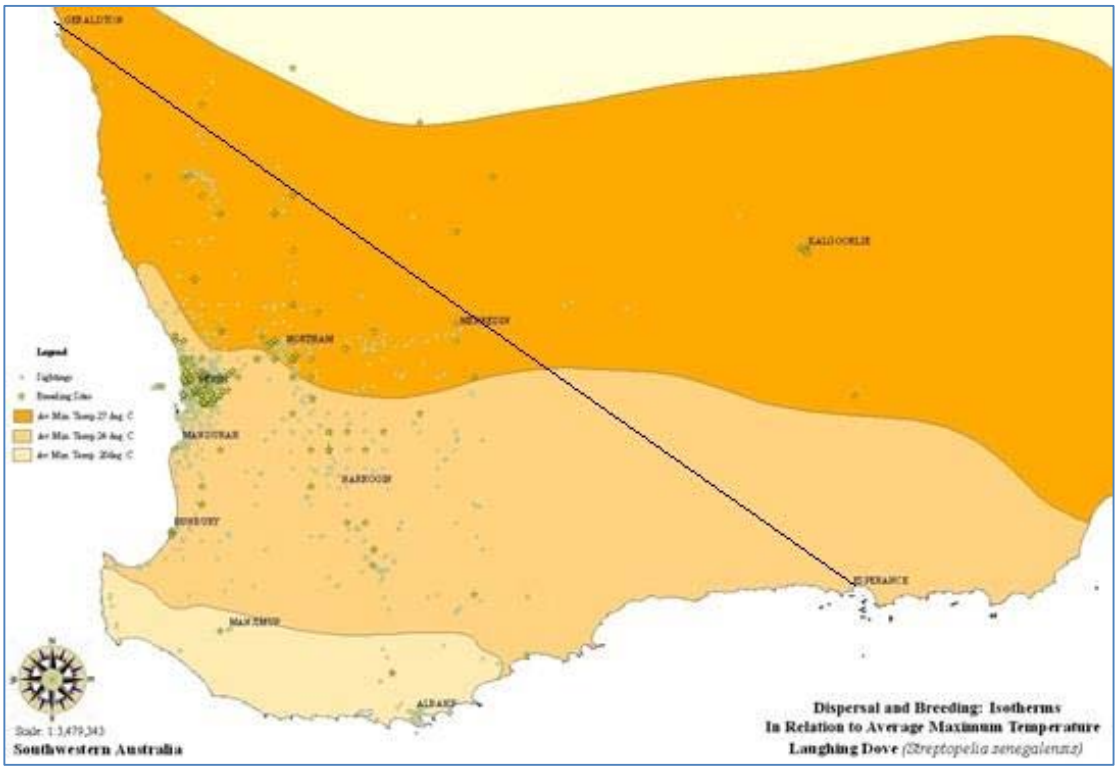
Map 6.12: Dispersal of Spotted Dove In Relation to Average Maximum Temperature
(All Eras: 1898 – 2007) (Includes Breeding)

The data is represented as: Sightings 1898-2007 (•) Breeding 1898-2007 (☆) and Temperature zones 27°C (□); 24°C (□); and 20°C (□) (Map 6.12). Whilst the dispersal of the Spotted Dove extends throughout all temperatures zones, the population is concentrated in the moderate 24°C zone, as are the majority of breeding records for the species. The intensely settled metropolitan area is also situated in this zone.

Historically, in other parts of Australia and other countries where it has been introduced, the species has avoided rural areas and sustained only a localised metropolitan population that is seldom more than 100km outside of urbanised areas.

Although, individuals released in the warmest sector (27°C) in Era A, 1898-1953, in the north-east sector, at Yatheroo failed to establish permanent populations. Whilst in the cooler temperature zone further south, there were intermittent sightings recorded for Era B, 1954-1980 and Era C, 1981-2007. This suggests that the species is less tolerant of conditions in the warmer temperature zone.

However, if either the warmer climatic conditions to the north; or cooler climatic conditions to the south of the main population were the major environmental factor influencing site selection, a clear shift into these areas over time would be evident. Therefore it is unlikely that temperature is the main determinant in habitat selection.



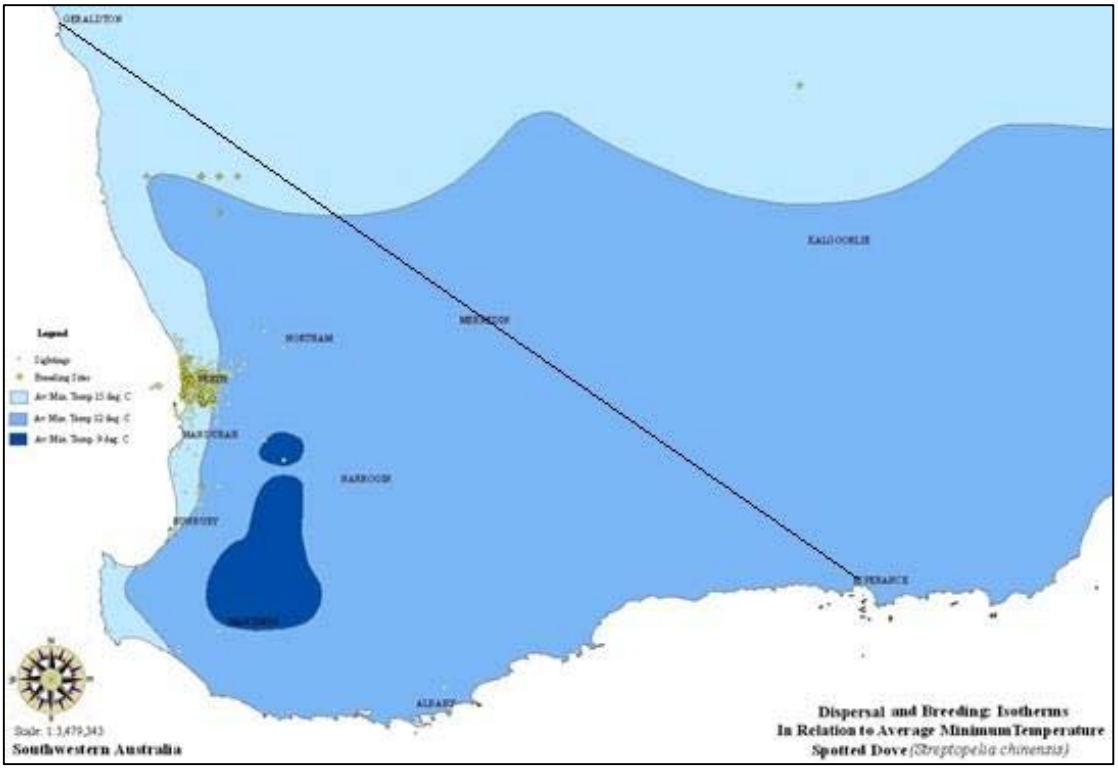
Map 6.13: Dispersal of Laughing Dove In Relation to Average Maximum Temperature
(All Eras: 1898 – 2007) (Includes Breeding)

The data is represented as: Sightings (•) Breeding (□) and Temperature zones 27°C (□); 24°C (□); and 20°C (□) (Map 6.13). Whilst the dispersal of the Laughing Dove also extends across all temperatures zones it is also concentrated in the 24°C zone. The next highest distributions are situated in the warmer 27°C zone. As with the Spotted Dove, it is probably other factors than temperature that influence the distribution of the species. The concentration of sightings and breeding in and around the metropolitan area is in all probability linked to the availability of food and shelter found in urban areas, rather than the moderate temperature of the area.

The presence of, and breeding by, the species in the hottest zone in the north and north-eastern sectors indicates the species can tolerate these conditions. However numbers remain low and the species is widely dispersed. The area is at the tip of the northern Wheatbelt region and is the geographic limit of a landscape that affords the ecological advantages characteristic of the dryland agriculture environment.

Similarly, the coolest sector, in the southernmost region of the study area, is heavily wooded and supports extensive tracts of conserved and protected bushland areas. The majority of sightings recorded for the zone are situated within areas that have been cleared for agriculture and urban settlements. However, the presence of the species in these zones indicates that it is able to live and breed within this temperature zone. It is therefore probable that other factors present a barrier to spread.

6.7.8 Dispersal in Relation to Average Minimum Temperature:

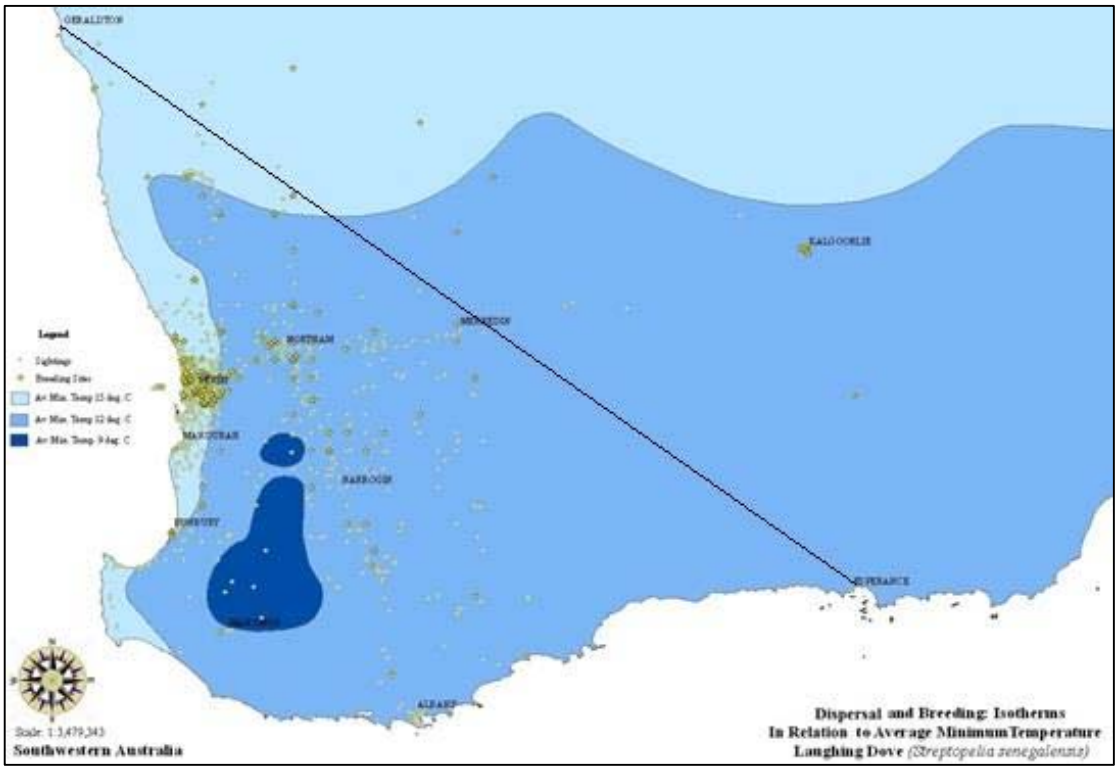


Map 6.14: Dispersal of Spotted Dove in Relation to Average Minimum Temperature
(All Eras: 1898 – 2007) (Includes Breeding)

The data is represented as: Sightings 1898-2007 (•) Breeding 1898-2007 (☆) and Temperature zones 15°C ( ); 12°C ( ); and 09°C ( ) (Map 6.14). Similarly, distribution of the Spotted Dove in Relation to Annual Minimum Temperature extends across all temperature zones. The sightings concentrated in the metropolitan area fall within the 15°C zone and those north and south of the metro area either in, or along the edge of the 12°C zone. There are very few sightings in the areas of the lowest minimum temperatures.

The areas that record the lowest temperatures are situated well outside the metropolitan area and contain only occasional sightings. However, it is probably other environmental factors than temperature that are the barrier to spread. The area along the coast south of Mandurah to Denmark (west of Albany) contains resource protected areas. The bushland terrain supports a dense understorey vegetation which has few foraging opportunities for the ground-feeding dove.

Ecologically, it is advantageous for the species to remain in proximity to areas of human settlement, in highly modified habitats, as returns are high on the energy expended foraging, nesting and finding suitable roosts; whereas a push into natural areas demands greater energy expenditure for reduced benefits.



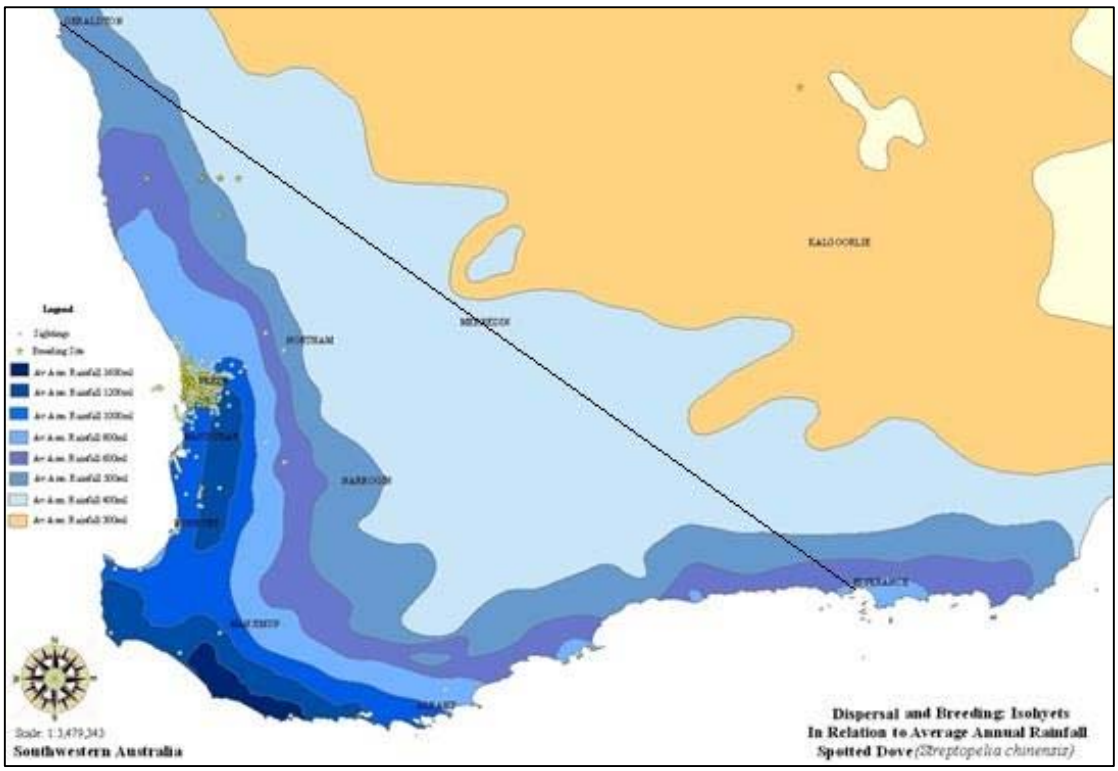
Map 6.15: Dispersal of Laughing Dove In Relation to Average Minimum Temperature
(All Eras: 1898 – 2007) (Includes Breeding)

The data is represented as: Sightings (•) Breeding (□) and Temperature zones 15°C ( ); 12°C ( ); and 09°C (□) (Map 6.15). Similarly, distribution of the Laughing Dove in Relation to Annual Minimum Temperature extends across all temperature zones. The majority of sightings (including breeding) are situated in and around the metropolitan area, in the 15°C zone; with most of the remaining sightings situated in the 12°C zone. The fewest sightings (no breeding), lie within the coolest 09°C zone. The absence of breeding in this zone is probably due to habitat conditions rather than temperature; otherwise breeding would have occurred there in the warmer months.

Again, as with the Spotted Dove, the low incidence of sightings on the Southwest Peninsula is probably more attributable to habitat conditions than temperature as it lies within the warmest sector, and the species has shown it can live in much cooler conditions. However, it favours modified habitats and the landscape of the Southwest Peninsula retains extensive tracts of bushland. Although transport routes pass through, they do not offer optimal foraging opportunities.

Most of the inland sightings apart from those in the 12-15°C zones, are aligned with transport routes used to service grain storage and transport which provide optimal foraging opportunities. They also provide pathways through usually inaccessible habitat as well as provide some roosting and nesting sites and act as an aid to dispersal.

6.7.9 Dispersal in Relation to Average Annual Rainfall:

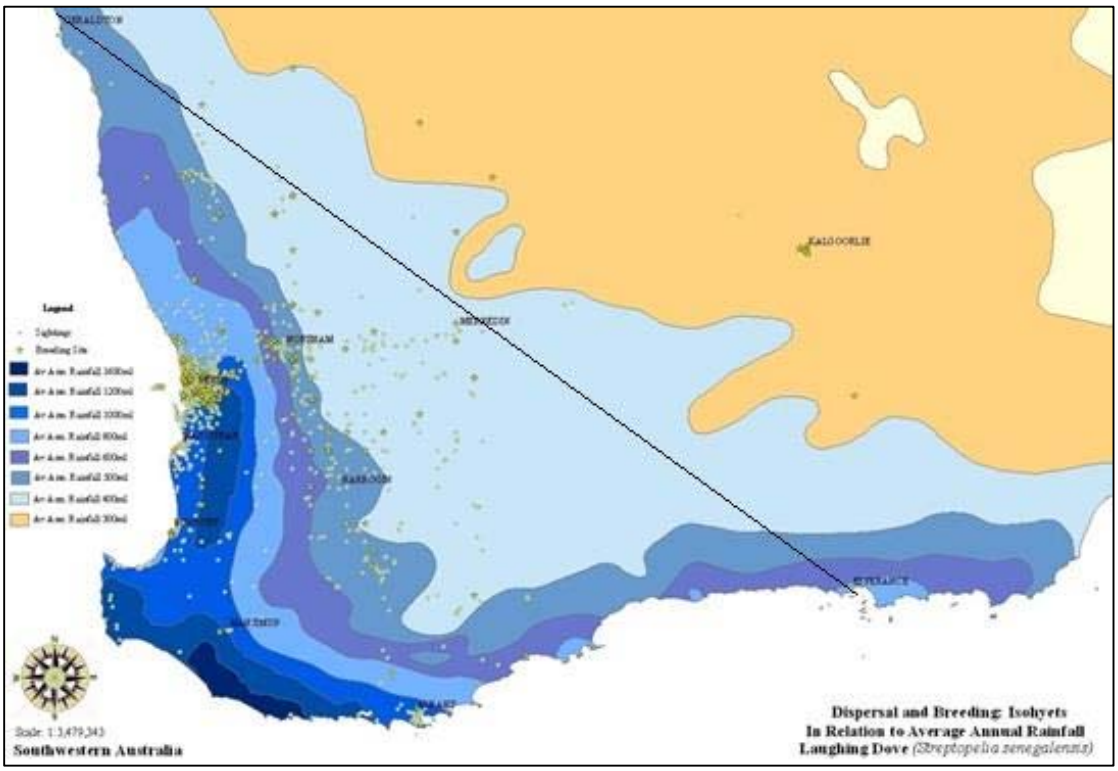


Map 6.16: Dispersal of Spotted Dove in relation to Average Annual Rainfall (Isohyets)
(All Eras 1898 – 2007) (Includes Breeding)

The data is represented as: Sightings 1898-2007 (•) Breeding 1898-2007 (☆) and Rainfall zones: 1600mm (□); 1200mm (□); 1000mm (□); 800mm (□); 600mm (□); and 500mm (□) 400mm ( ). The arid zone (□) (≤ 300mm) falls outside of the study area limits (Map 6.16). The distribution of the Spotted Dove in Relation to Annual Average Rainfall extends across all zones. The bulk of the sightings, however, fall within the 800-1000mm zones, although breeding has occurred in the lower (400-600mm); and higher (1200mm) rainfall zones. This suggests that the actual extent of rainfall is not a key factor in breeding.

However, it may be a major influence on the overall distribution of the species. For despite sharing an almost identical ecological profile to the Laughing Dove in terms of roosting, feeding and breeding requirements, the Spotted Dove, with its evolutionary origins in moist tropical-to-sub-tropical climes, has failed to colonise the interior.

The inland environment experiences steadily declining rainfall that decreases eastwards towards the study area boundary. It is an environment quite unlike the moist, tropical areas from which the species originates from. It is also much drier inland than along the coastal belt.



Map 6.17: Dispersal of Laughing Dove in relation to Average Annual Rainfall (Isohyets)
(All Eras 1898 – 2007) (Includes Breeding)

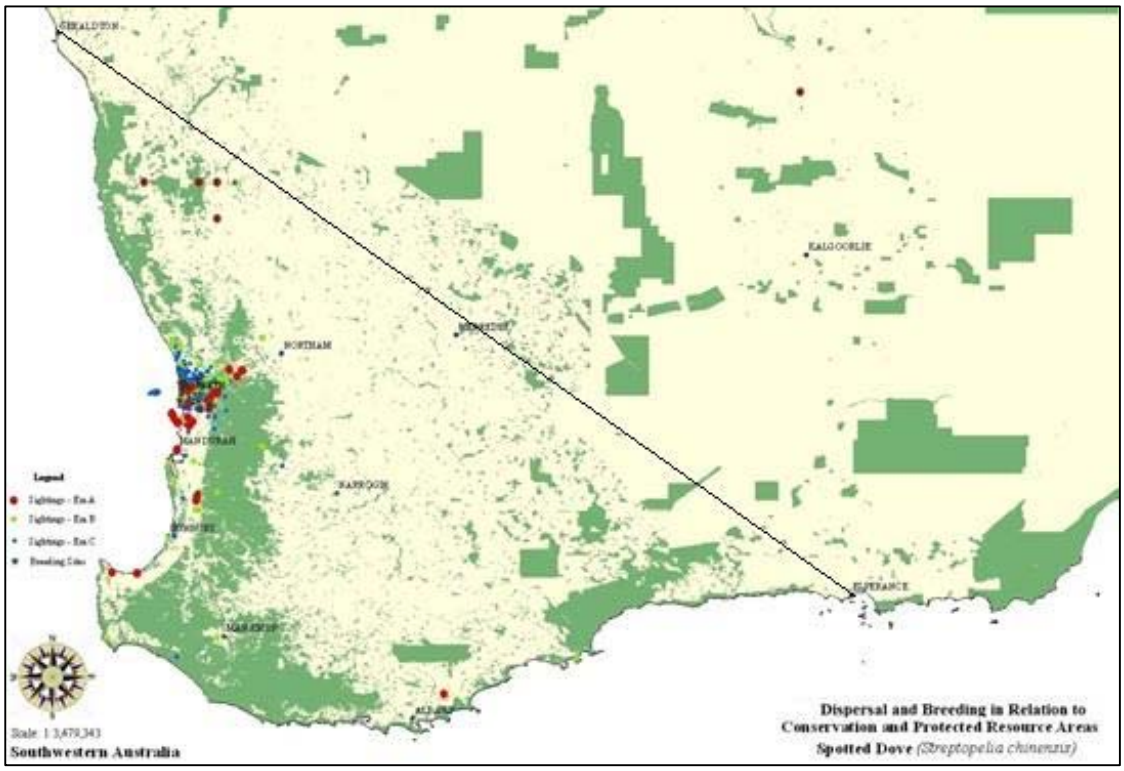
The data is represented as: Sightings (•) Breeding (☆) and Rainfall zones: 1600mm (□); 1200mm (□); 1000mm (□); 800mm (□); 600mm (□); and 500mm (□) 400mm ( ). The arid zone (□) (≤ 300mm) falls outside of the study area limits (Map 6.17). The distribution of the Laughing Dove in Relation to Annual Average Rainfall also extends across all zones. As with Spotted Dove the population, and breeding, are concentrated within the 800-1000mm zones. It has also colonised isolated areas outside the study area that receive as little as 400mm annually.

The inland populations within these low rainfall zones occupy habitat associated with dryland agriculture. Unlike the pastures of the coastal south-west, the broadacre fields are not irrigated. Other than rainfall however, water can be sourced from homestead dams and tanks; de-commissioned railway dams once used in service of steam locomotives, and inland lakes linked to ancient drainage patterns.

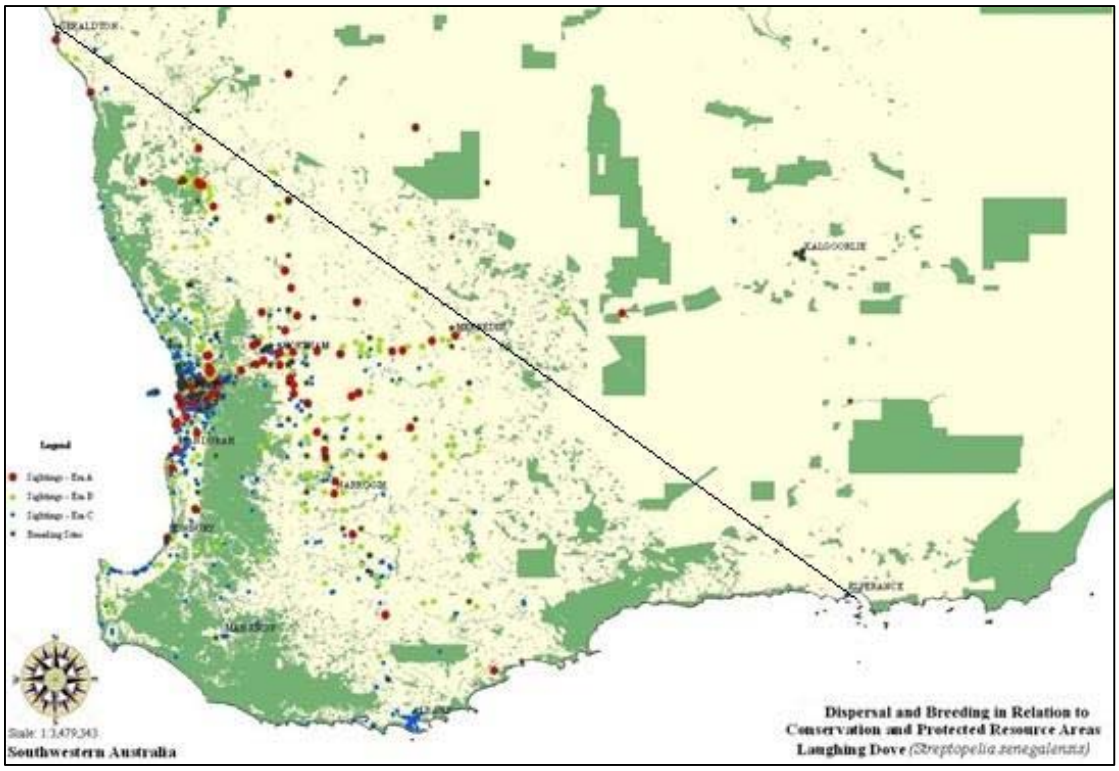
The lineal distribution of the species across the 500-600mm zones south-east from Northam parallel road and rail routes that service grain storage and suggests that accessibility rather than rainfall is the main influence on distribution, although rainfall levels can affect food supply. These lower rainfall zones are congruent with the 24°C annual average temperature zone; this combination allows spilled or blown grain to germinate and renew, thus ensuring a constant food supply.

It is the type of environment in which the Laughing Dove, which originates from hot, arid countries, has long endured in and is well suited to.

6.7.10 Dispersal in Relation to Conservation and Protected Resource Areas:



Map 6.18: Dispersal of Spotted Dove in Relation to Conservation and Protected Areas
(All Eras: 1898 – 2007) (Includes Breeding)



Map 6.19: Dispersal of Laughing Dove in Relation to Conservation and Protected Areas
(All Eras: 1898 – 2007) (Includes Breeding)

The data for the Spotted Dove and the Laughing Dove in relation to 'Conservation and Protected Resource Areas' is represented by: Era A (•) 1898-1953; Era B (•) 1954-1980; and Era C (•) 1981-2007 and Breeding 1898-2007 (□) (Map 6.18 and Map 6.19). Once again the depiction of the data clearly identifies the dissimilarities in the distributions of the species. The spread of the Laughing Dove outside urban areas indicates its ecological flexibility and ability to adapt to other types of highly modified environments.

The strongest similarity in the distributions is that both are concentrated in the metropolitan area in close proximity to human settlements. These environments offer ecological advantages such as a constant and accessible food supply, as well as plentiful roosting and nesting sites.

In terms of the spread of the species beyond urban confines, the data show that initially, during Era A, 1898-1953, *Introduction, Death or Captivity* phase, both species breached the 'bush barrier' of the eastern Darling Ranges to settle localities including Kalamunda, Gooseberry Hill, Bickley, Helena Valley, Greenmount, Darlington, Glen Forrest, Hovea, Parkerville, Stoneville and Mundaring. They also settled near the outlying settlements of Gidgegannup, Chidlow and Wooroloo. However, only the Laughing Dove moved beyond the urban-rural fringe into the more isolated settlements of Northam and York and then dispersed throughout the Wheatbelt area.

The expansion by the Spotted Dove through the eastern hills terminated at around Wooroloo in Era A, 1898-1953; and Era B, 1954-1980, the range extent of the species had begun to contract. This trend continued into Era C, 1981-2007. By the close of the period, the presence of Spotted Dove did not extend beyond the hills settlements.

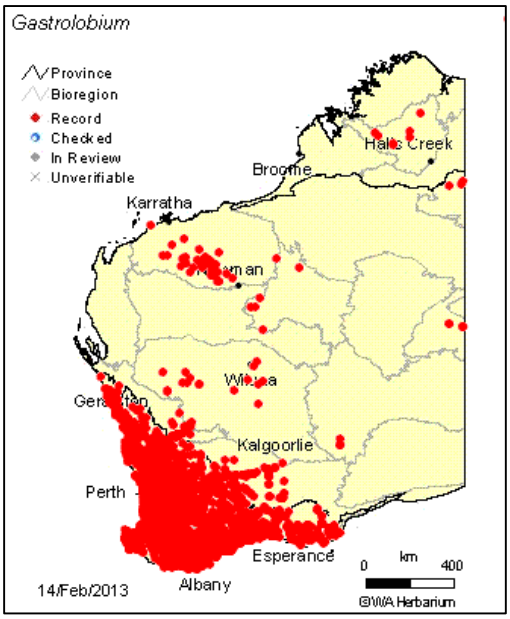
At the time both species were released, and throughout the Era A period, the habitat of these semi-rural enclaves would still been heavily wooded with only a few scattered human habitations. The push of both species into these areas was probably due to the habit of the species to follow along transport routes cleared of vegetation.

The limited success of both *Streptopelia* species in settling bushland areas, has been previously noted, and says Teague, it "is perhaps significant that individuals penetrate into 'the bush' but apparently do not settle" (in Sedgwick, 1958a, p. 93). The observation becomes strikingly significant when the distributions of both species are considered in relation to the distribution of conservation areas outside the metropolitan area.

The data for all stages show that at no stage subsequent to colonisation did either species penetrate the 'bush barrier' of the wet sclerophyll forests of the south-west sector. Although there are a few scattered sightings in the surrounding area, these are probably confined to towns and smaller settlements. Whilst the Laughing Dove did spread into rural areas, these lay to the east of the sclerophyll forests, in the Northern Central and Southern Wheatbelt areas, which have been extensively cleared of vegetation. Neither species has pushed north along the coast into areas that support remnant vegetation of the Geraldton Sandplains.

It would appear that areas of natural bushland habitat present an ecological barrier to both the *Streptopelia* species; each which is known to favour modified habitats. Modified habitats are more invasible and provide a constant and accessible source of both natural and alternative ecological resources; whereas natural habitats are harder to penetrate and sustained survival within these types of environment demands intensive energy expenditure in the procurement of food supply and the upkeep of territories to exclude competition for suitable roosting and nesting sites.

However, an alternative hypothesis as to why the *Streptopelia* species has failed to colonise the bushland habitats of the Southwest region has been proposed by ornithologist Dr. S.J.J.F. Davies. It relates to the occurrence of a particular tribe of plants, 'Mirbelieae', to which poisonous *Gastrolobium* R. Br. belongs. The tribe consists of 109 species, and belongs to one of the largest legume genera of region and forms "a major component of the understorey in many areas" (Chandler, Crisp, Cayzer, & Bayer, 2002, p. 619) (Map 6.20).



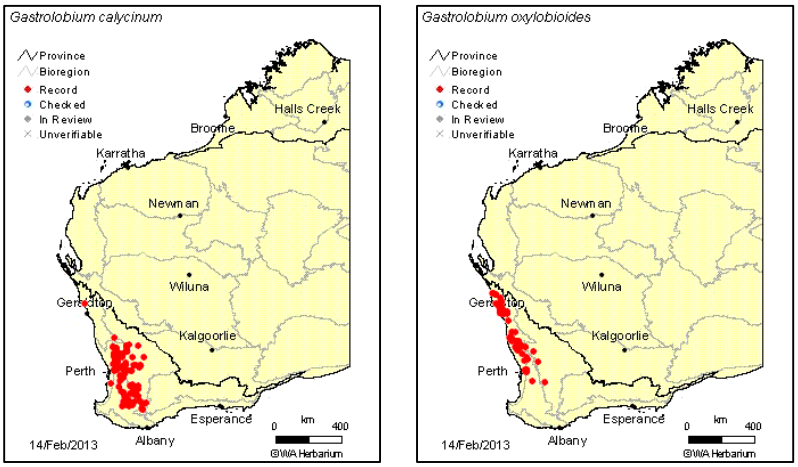
Map 6.20: Distribution of *Gastrolobium* R. Br. in Western Australia
(Source: Western Australian Herbarium, 2013c)

The *Gastrolobium* plant produces a variety of orange, yellow and red flowers (Plate 6.16). The colourful appearance of the plant possibly proclaims its toxicity, which contains the sodium salt of 'monofluroacetic acid'. The toxicity of the plants was first discovered in the 1830s after tests were conducted to ascertain what was causing ruinous livestock losses, although the actual toxin was not identified until the late 1960s (Chandler *et al.*, 2002). The plant toxin has been adapted for use in the production of commercial poison 'Compound 1080' that is widely used to control pests including foxes and feral cats in the study area and other parts of the world.

Plate 6.16: *Gastrolobium* Plant
(Photograph: Western Australian Herbarium, 2012)

Of the many species of *Gastrolobium*, two in particular have been identified as being highly toxic, *G. calycinum* and *C. oxylobiodes*. The distributions of which (Map 6.21) correspond with areas the Spotted Dove and the Laughing Dove have failed to colonise. Other varieties: *G. lehmanni*, *G. luteifolium*, *G. modestum*, and *G. papilio*, are now rare or threatened due to intensive eradication as a means of limiting livestock losses (Chandler *et al.*, 2002).

The toxic compound of the plant is located in endoderum, rather than the seed testes. Its function is probably to act as a toxic store for seedlings to utilise during vulnerable stages of growth. Just as the *Gastroloblium* "evolved the ability to synthesise monofluroacetic acid, native herbivores apparently co-evolved a tolerance to this toxin" (Chandler *et al.*, 2002, p. 620) and learned to avoid the most toxic varieties and harmlessly ingest non-fatal amounts of the toxin.



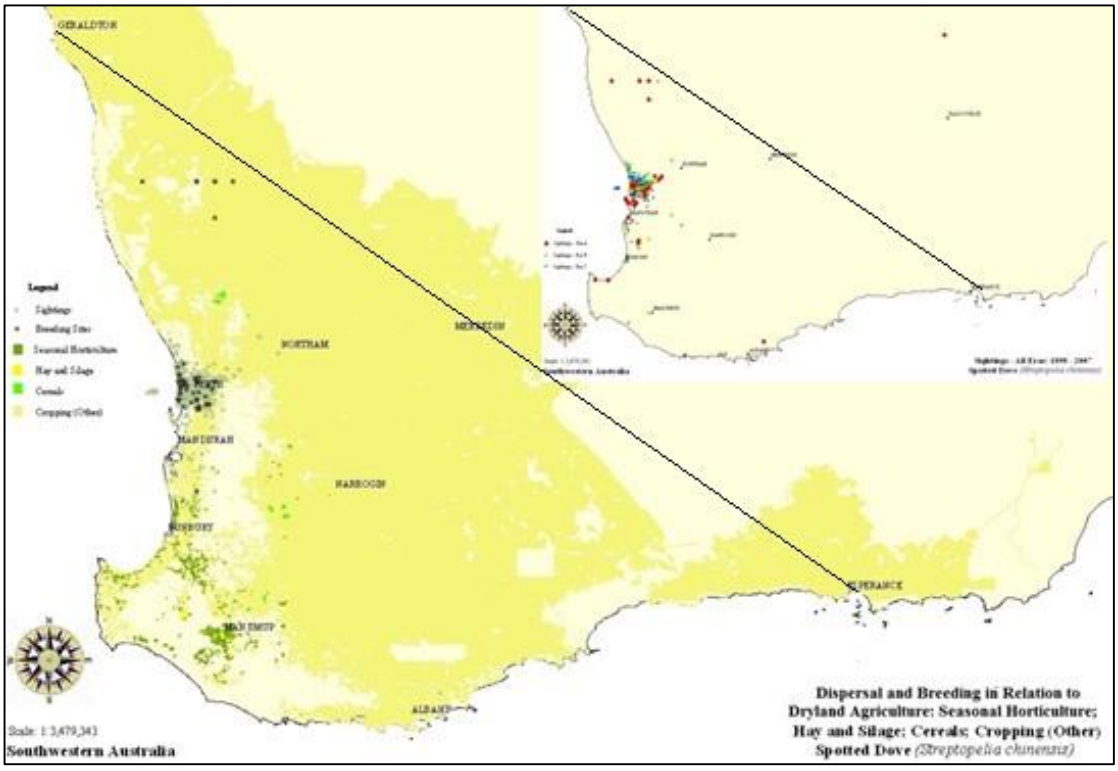
Map 6.21: Distribution of *G. calycinum* and *G. oxylobiodes* in Study Area
(Western Australian Herbarium, 2013a, 2013b)

However, as introduced species the Spotted Dove and Laughing Dove did not co-evolve with the toxic plant and consequently lack the intrinsic adaptation inherent in local species to avoid ingesting the toxic seeds, and any resistance to the poison. A possible scenario is that both species commenced to penetrate natural areas where *Gastrolobium* is present and fed on the noxious seeds. Although spread throughout the study area, as a food source, *Gastrolobium* is only critical in natural bushland settings, as urban and cultivated habitats provide other food sources.

This ecological barrier to spread into these natural areas may weaken as time progresses. Firstly, there are concerns *Gastrolobium* stocks may fail to recover from the efforts to eradicate it; a situation exacerbated by the sensitivity of the genera to chemical fertilisers, pest control sprays and pre-emergent weed sprays. The latter in particular are a dire threat as they prevent the *Gastrolobium* seed from germinating. The other scenario that may present is that as time passes and generations of the introduced doves become an incorporated component of the core ecological community of the study area, like native species, they too may develop an evolved ability to avoid the toxic plant, or develop immunity to its effects.

This concludes discussion on a possible ecological 'barrier' to the spread of the *Streptopelia* doves. The final aspect to discussion on the dispersal of the species is in relation to landuse practices and anthropogenic processes that act 'bridges' to spread. The proceeding discussion is limited to the spread of the Laughing Dove into areas of dryland agriculture, specifically in relation to associated infrastructure.

6.7.11 Dispersal in Relation to Dryland Agriculture and Associated Infrastructure:

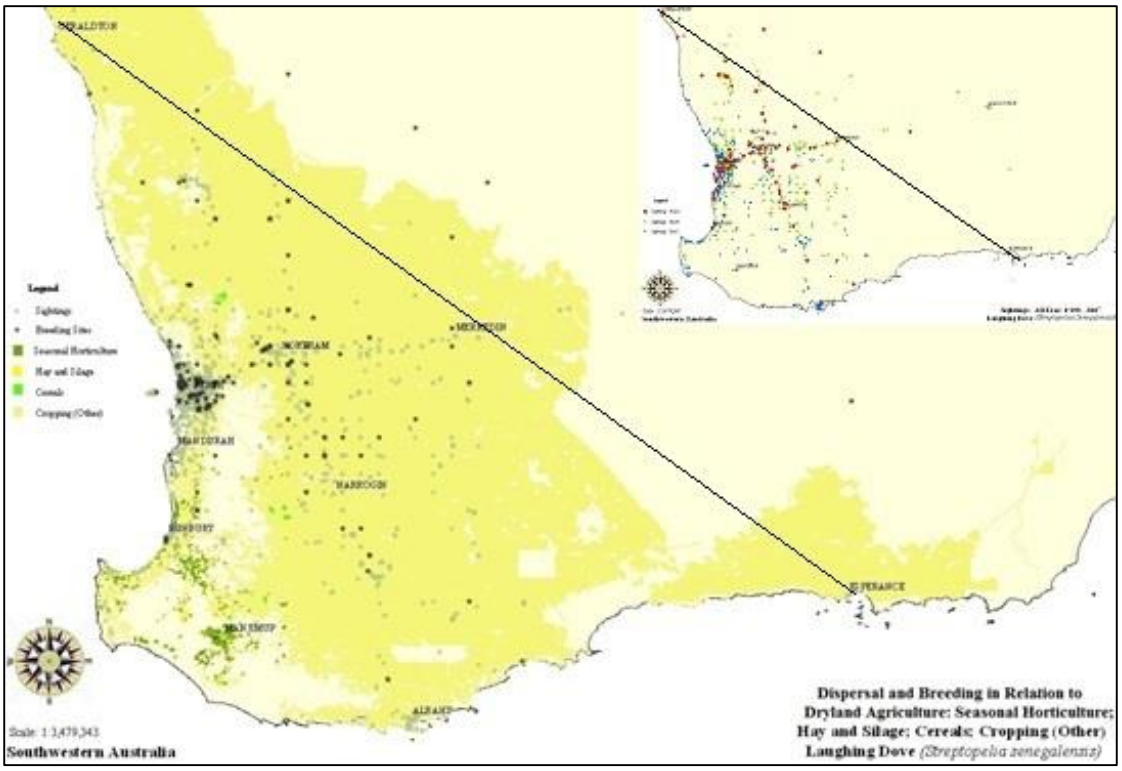


Map 6.22: Dispersal of Spotted Dove in Relation to Dryland Agriculture
(All Eras: 1898 – 2007) (Includes Breeding)

The data for the Spotted Dove in relation to Dryland Agriculture is represented by: Sightings 1898-2007 (•); Breeding 1898-2007 (☆); Seasonal Horticulture (□); Hay and Silage (□); Cereals Cropping (other) (□). Map inset: Era A (•) 1898-1953; Era B (•) 1954-1980; and Era C (•) 1981-2007) (Map 6.22).

A report in Sedgwick (1958a, p. 93) by B.V. Teague states that both the Spotted and the Laughing Dove "thrive in the vicinity of habitations and tend to colonise towns, only rarely establishing themselves in purely rural areas". Whilst this is true of the dispersal of Spotted Dove within the study area, it is not so for the Laughing Dove which has spread widely in agricultural areas). Whilst there are a few sightings of the Spotted Dove (including breeding) in dryland agricultural areas in the north-east sector in Era A, they reduce in Era B, and by Era C, there are no sightings in the area.

To the south, Era A sightings near Bunbury, on the Southwest Peninsula and near Albany were not sustained by breeding and also steadily diminish throughout subsequent eras. The decline of the species in these areas suggests it did not possess the flexibility demanded of it to survive in these sporadically settled areas. As a consequence, the dispersal of the species contracted to within urban confines. Unlike the Laughing Dove, it did not spread into areas of dryland agriculture, possibly due to a lesser tolerance of a low moisture threshold. Discussion will now focus on the spread of Laughing Dove into these areas; including its utilisation of associated infrastructure i.e. roads and railways.



Map 6.23: Dispersal of Laughing Dove in Relation to Dryland Agriculture
(All Eras: 1898 – 2007) (Includes Breeding)

The data for the Laughing Dove in relation to Dryland Agriculture is represented by: Sightings 1898-2007 (•); Breeding 1898-2007 (☆); Seasonal Horticulture (□); Hay and Silage (□); Cereals Cropping (other) (□). Map inset: Era A (•) 1898-1953; Era B (•) 1954-1980; and Era C (•) 1981-2007) (Map 6.23). The widespread dispersal of the Laughing Dove into rural areas is primarily in association to areas of Dryland Agriculture i.e. production of cereal crops; rather than 'country' areas *per se* (as discussed in the previous section, page 199).

The majority of landholdings in these areas were given over to wheat production, hence the region being named the 'Wheatbelt'. However other feed grains and fodders such as oats, barley and lupins were also produced.

As discussed in the previous section, the Laughing Dove is not well represented in localities to the southeast of Perth, on the Southwest Peninsula or to the west of the Great Southern road and rail networks: areas, which other than the metropolitan area, are the most intensely settled in the State. These areas also support extensive tracts of wooded 'Conservation and Protected Resource' habitat.

As detailed previously in the section, *Chronology of Dispersal* (shown inset), the push of the Laughing Dove into areas of dryland agriculture commenced within the first few decades of its liberation, in Era A, 1898-1953. A plausible scenario is that both species trailed rail and road networks to breach the 'bush barrier' of the Darling Ranges.

For the Laughing Dove, which was less sensitive to the low moisture threshold of the eastern realms, this facilitated a further movement inland along transport routes, into Northam and York. From these centres it spread widely across the Northern, Central and Southern Wheatbelt.

The Era B, 1954-1980, phase data, displays two noteworthy aspects related to the dispersal of the species: (a) an increasing (intensity in the) frequency of sightings; and (b) constant range expansion. It also displays:

- Clumping around Era A sites i.e. indicating utilisation of available ecological resources in isolated habitat patches;
- Linear progression of spread e.g. eastward from Perth through Northam to Merredin and beyond; and south-east from Northam to Narrogin and Katanning; and Stepping-stone dispersal e.g. from Bunbury on the southwest coast, inland to Manjimup, Boyup Brook and Kojonup in the southeast corner.
- Contraction of Era A distributions in the north-east sector.

The range contraction becomes more manifest between Era B and Era C, 1981-2007, *Spread, or Remain Local* phase, by which time spread has constricted to within Era B limits in the north-east, east and south-east sectors. Principally, these shifts in distribution of the Laughing Dove throughout the Wheatbelt exhibit the species response to altered ecological conditions wrought by anthropogenic change i.e. changes in grain storage and transport methods.

The development of the West Australian grain industry can be viewed in stages: 1829-1838, *Survival Period*, as in term of learning to cultivate crops in a new environment; 1839-1889, *Inventive and Expansion Period*, introduction of 'power', i.e. mechanised farm equipment, and notably, the steam engine which changed the movement of produce to rail rather than river transports; 1890-1940 the *Transition Period*, advances in bulk grain handling and storage; and transportation; and 1941- present, *Technology Period*, the introduction of digitised equipment, communication tools, and the expansion of the local market into the global economy (Bell, 2006).

In relation to the impacts of these phases upon the distribution of the Laughing Dove, it is the combined periods 1839-1940 that are important. The agricultural practices applied at these times, in terms of production, harvest and transport, proved an ecological boon for this highly adaptive species. At the time of its release in 1898-99, "bagged grain was the only option for exporting or transporting grains" (Bell, 2006, p. 35).

Harvesting was carried out using beasts of burden (horses or bullocks) attached to a header machine (Plate 6.17). The equipment was not refined and some seed was spilled or missed during the process. The harvested produce was then threshed and augured into bags in the fields (Plate 6.18). The fibrous hessian bags were then stitched closed in readiness for transportation. More grain was spilled during bagging.

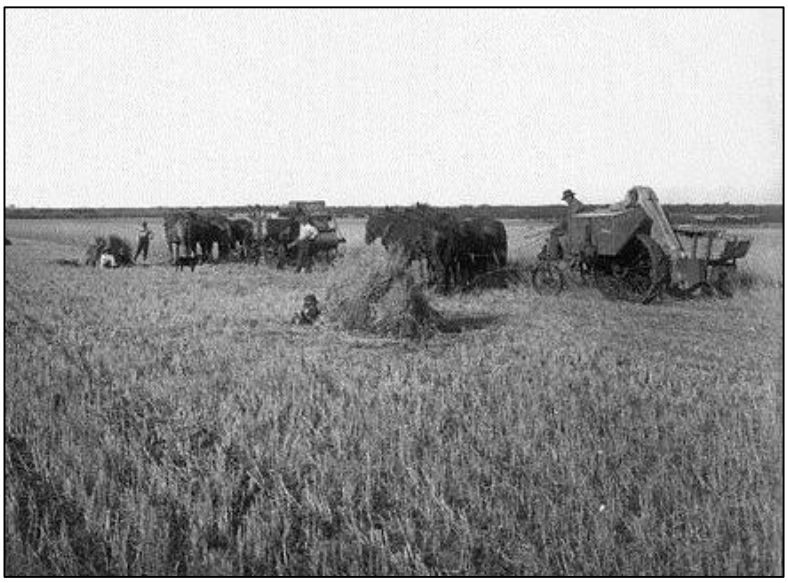


Plate 6.17: Harvesting and stripping grain, WA
(Battye Library, *Circa* 1922)

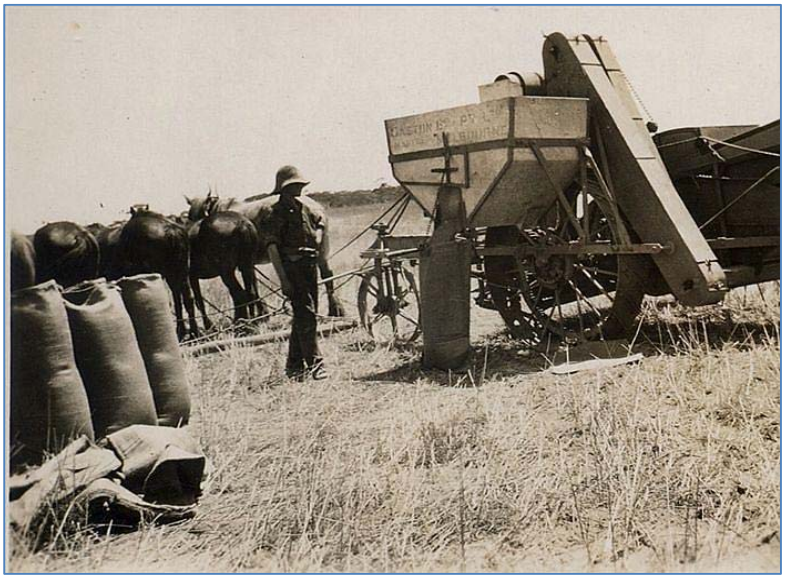


Plate 6.18: Auguring and bagging grain, WA
(Battye LIbrary, *Circa 1920s-a*)

By the mid-1920s, the design of farming machinery had improved and equipment was motor driven. Whilst these advances reduced wastage to some extent, some of the yield was still missed or spilled in the process from harvest to bagging. Whilst motorised cartage also came into use, produce was still transported in bags (Plate 6.19and Plate 6.20).

Spillage during transport was common as a result of bags being poorly sealed, or splitting from handling or the weight of stacking. The spilled grain provided an accessible and constant food supply for the Laughing Dove.

Other than the supply available along transport routes, grain could also be sourced from the fields: not just at harvest time, but at the time of planting and whilst it was growing and maturing.

Although facilities to handle bulk grain storage at rail sidings were built as early as 1931-32, the end of bagged wheat marketing did not cease until the 1950s (Bell, 2006). By this time the stock of spilled seed, wild germinated seed and sown seed was ample enough to provide food for the Laughing Dove for decades.

Plate 6.19:Loading bagged grain, Carnamah, WA
(Battye Library, 1927)

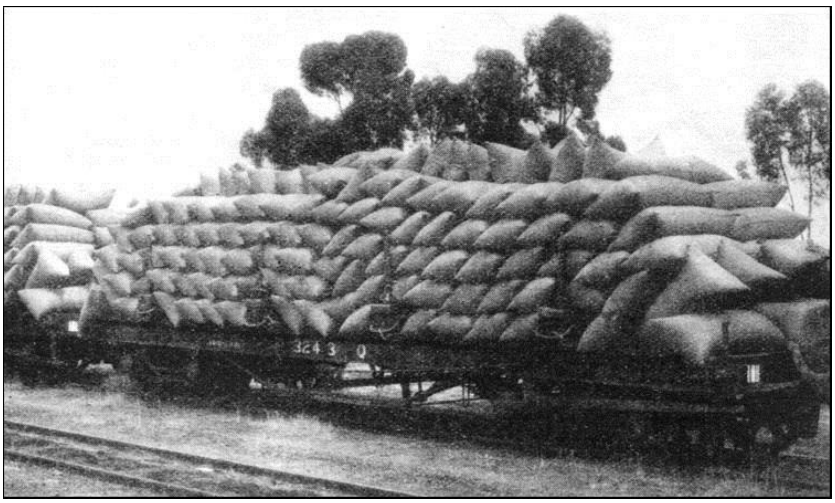


Plate 6.20:Bagged grain on railway wagon, WA
(Battye Library, *Circa 1920s-b*)

In Western Australia, the discovery of gold in the 1890s and the wealth it injected into the local economy funded the expansion of the railways into rural areas (Map 6.24). The rail system necessitated a network of tracks and roads to link between producers and the railway. Also, the steam driven locos had to be filled en route, so dams and tanks were located at various sidings and settlements.

These fixtures remained in place long after steam was replaced by diesel power. This artificial water supply, as well as that available on homesteads and farms, along with spilled grain in fields and along transport routes, opened up lands to the Laughing Dove that would otherwise have been uninhabitable (Map 6.25and Map 6.26).

As previously stated, by the late 1940s the Laughing Dove had colonised a number of Wheatbelt localities including Northam, York, Beverley, Brookton, Pingelly and Narrogin, By 1952 it had spread throughout grain producing districts and was "frequently encountered in open country between towns though generally at rail sidings and homesteads" (Sedgwick, 1958a, p. 94). From settlements the species trailed road verges between towns and used the cleared tracts that followed the rail:

> All rail sections along which the birds were noted were at the time, and indeed are still at the time of writing, being extensively used for the haulage of bulk grain, mostly wheat… and the not inconsiderable amount spilled from passing trains onto the open railroads would provide a useful supply of food for migrating individuals (Teague in Sedgwick, 1958a, p. 94).

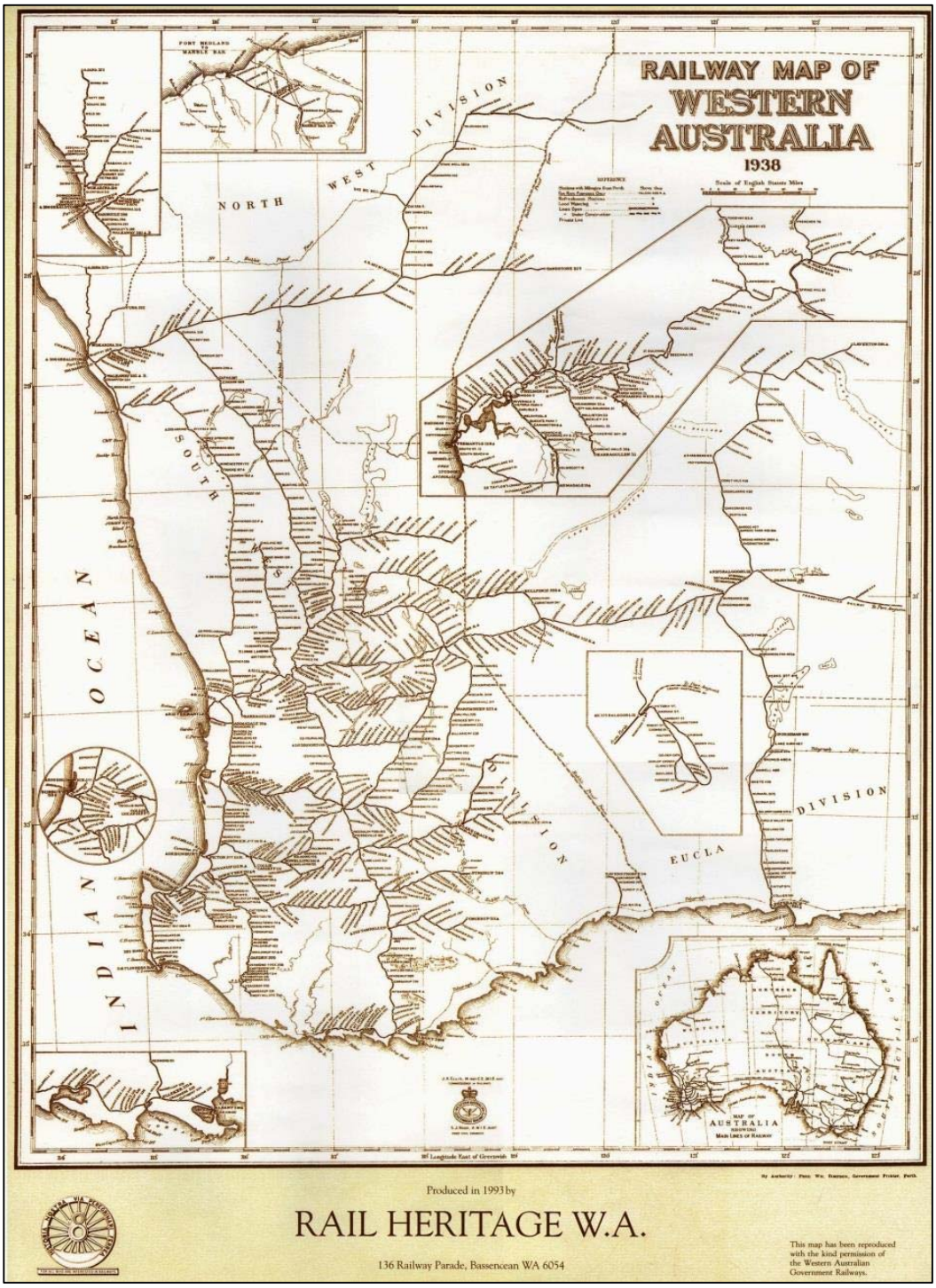
Other than providing a constant and accessible food source of spilled grain; the rail and road networks cut a path through bushland areas set aside for reserves and verges. This allowed the Laughing Dove to traverse habitat that was usually avoided. This seems a logical proposition given that soon after its release the species had spread into areas of dryland agricultural areas, cleared of vegetation; but was present only sporadically throughout the heavily wooded south-west sector.

With each passing era, grain production increased steadily, aided by technological advances: in farming equipment, fertilisers and pest control. Wheat strains were adapted to better suit the local environment. The increased yields necessitated changes in storage and transport methods. The marketing of wheat stored and transported in bags was phased out. By the end of the 1950s bulk handling equipment, storage and transport were standard practices for farmers and marketers (Plate 6.21; Plate 6.22and Plate 6.23).

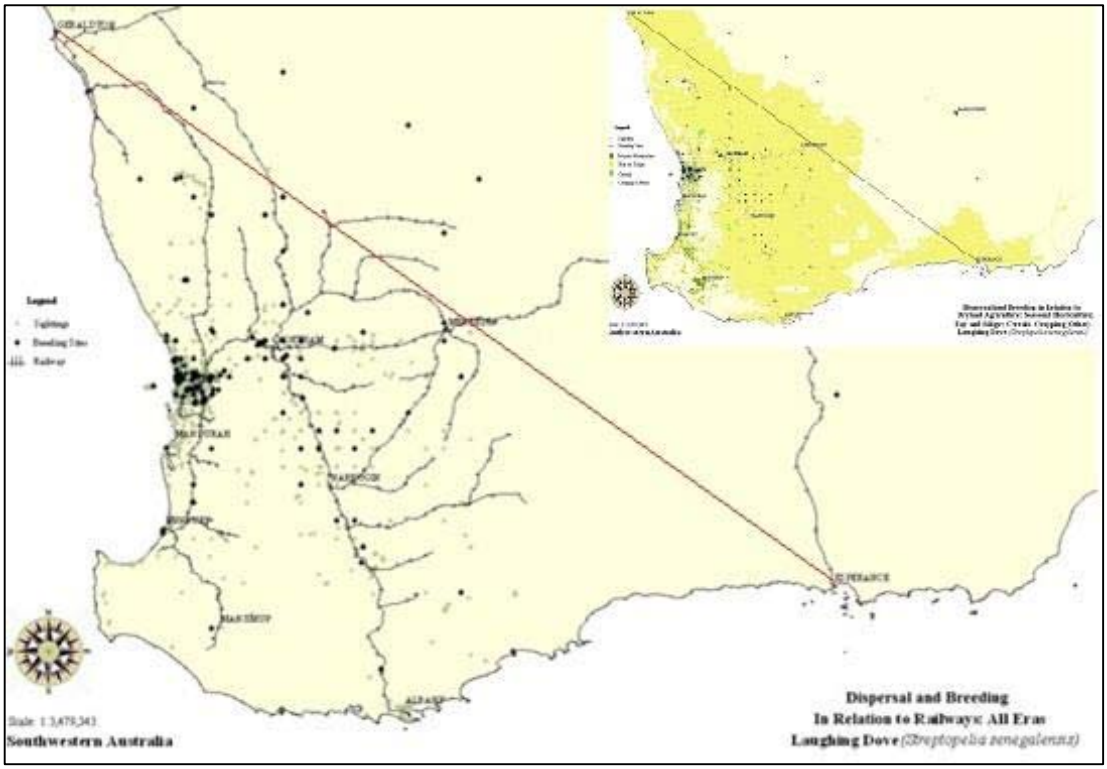
The arrival of these new practices had a marked impact on the dispersal of the Laughing Dove in grain producing areas. Whilst bulk handling did not entirely eradicate spilled grain as a food source for the species, it reduced it significantly.

In response to these changes the geographic distribution of the Laughing Dove contracted. The populations became concentrated around settlements, mainly those with grain storage facilities. Like their urban counterparts, the species utilised ecological resources found in environments close to human habitation. Its behaviour here simply reflecting its habits at home, having "come to town *via* the village where man's grain growing and above all, his provision of reliable water supplies created suitable living conditions for it" (Goodwin, 1978, p. 74).

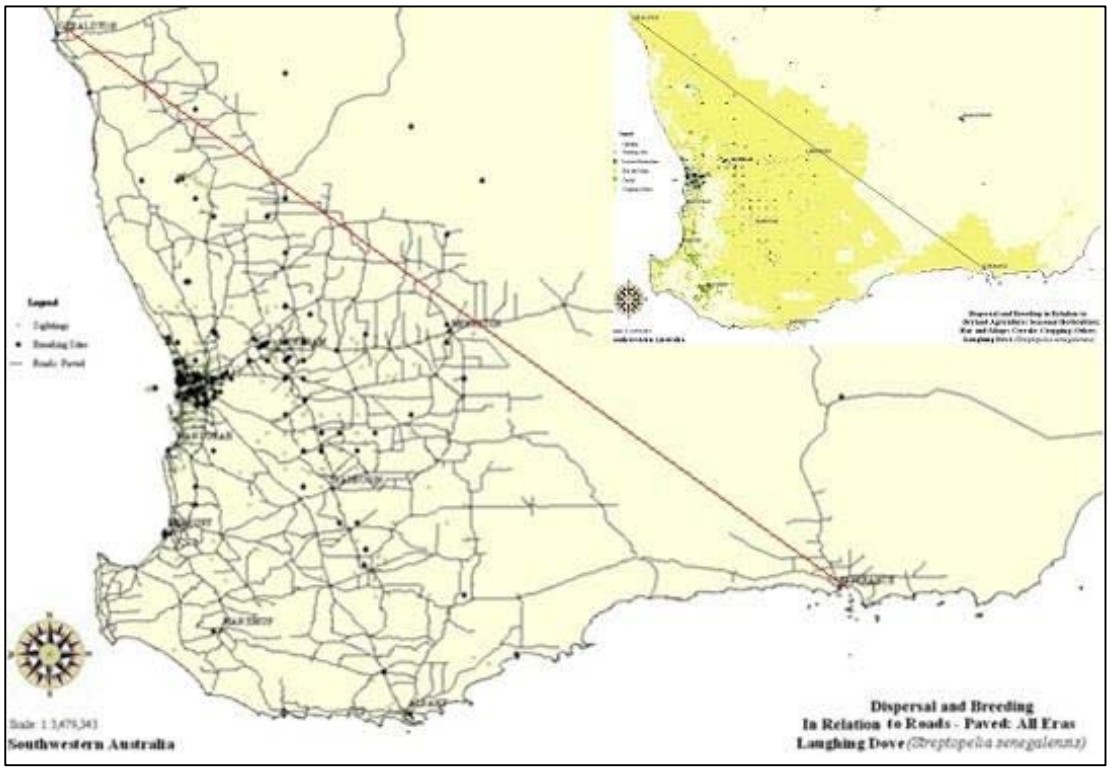
This concludes discussion on the dispersal of the Spotted Dove and Laughing Dove in relation to landuse and climate factors associated with the Study Area. Discussion now moves toward examination of the *Spatial Statistics* related to the distributions.



Map 6.24: Extent of railways, Southwest WA, *circa* 1938
(Rail Heritage Western Australia, 1993)



Map 6.25: Dispersal of Laughing Dove in Relation to Rail Networks
(All Eras: 1898 – 2007) (Includes Breeding)



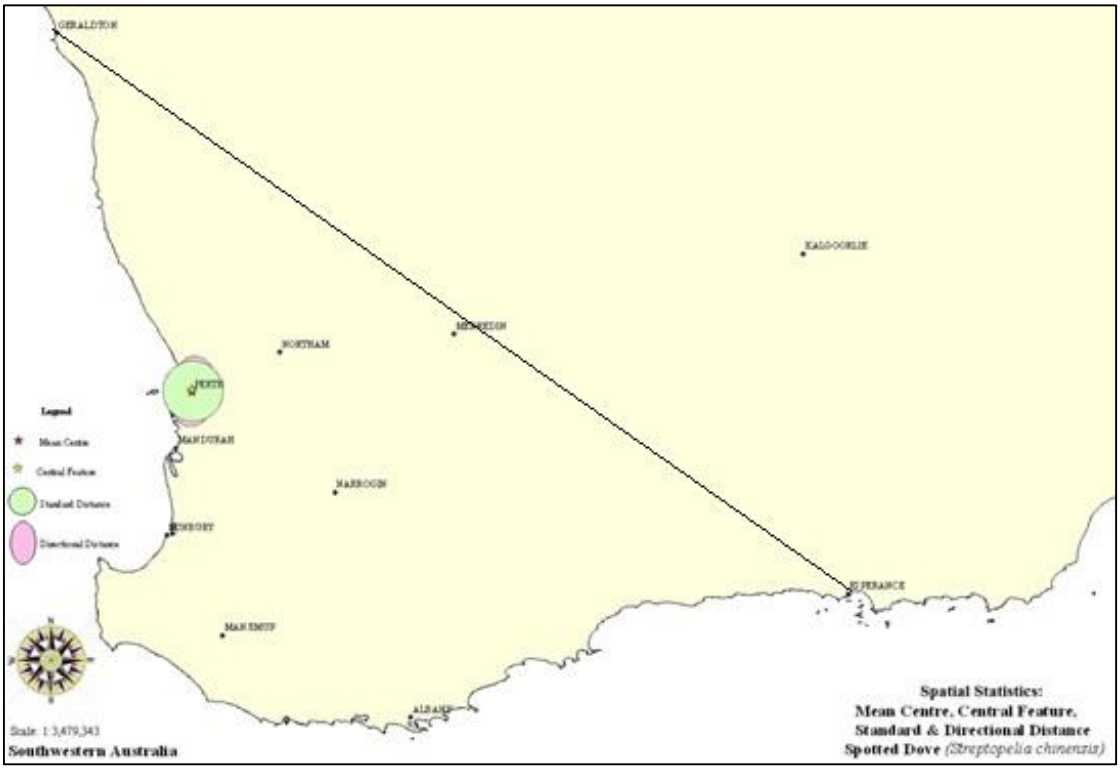
Map 6.26: Dispersal of Laughing Dove in Relation to Road Networks
(All Eras: 1898 – 2007) (Includes Breeding)

Plate 6.21: Bulk grain harvest, Wheatbelt, WA
(Harrison, 2012)

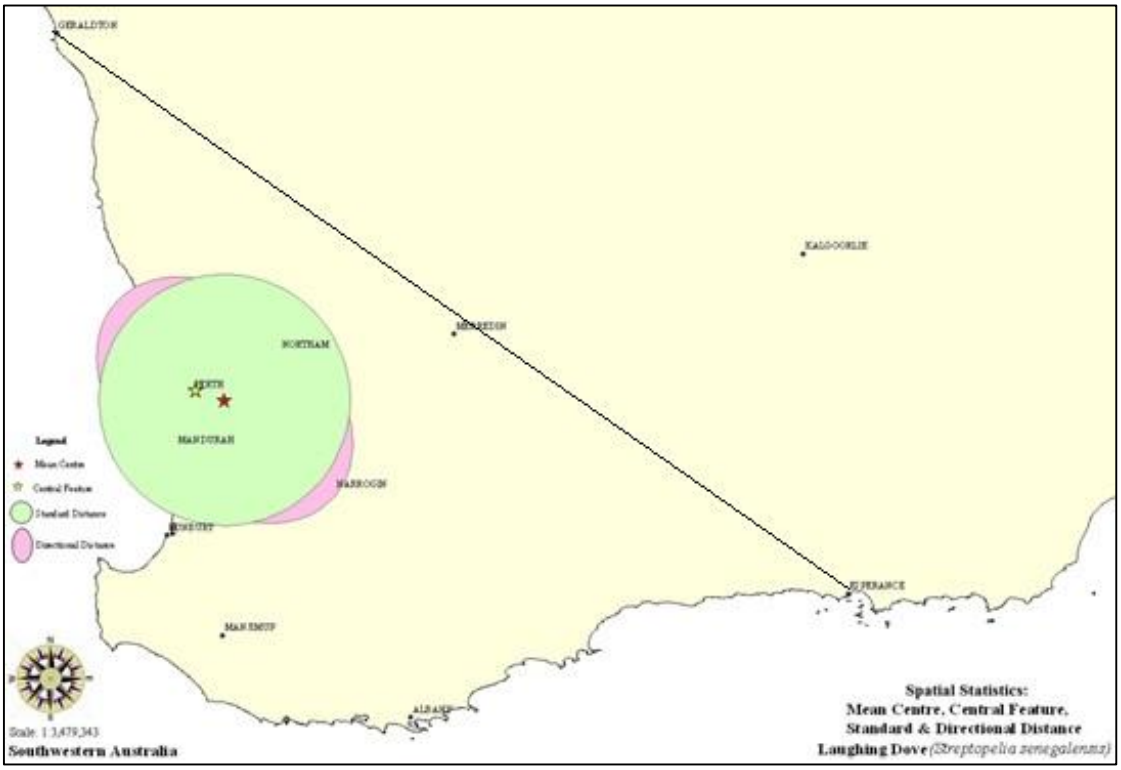
Plate 6.22: Bulk grain silo, on rail-line, Meckering, WA
(Mingor, 2009)

Plate 6.23: Grain silos, on Great Eastern Highway, Tammin, WA
(Rands, 2007)

6.7.12 Spatial Statistics:



Map 6.27:*Spatial Statistics*: Spotted Dove
Standard Distance, *Directional Distribution*, *Mean Centre* and *Central Feature*
(All Eras: 1898 – 2007)



Map 6.28: *Spatial Statistics*: Laughing Dove
Standard Distance, *Directional Distribution*, *Mean Centre* and *Central Feature*
(All Eras: 1898 – 2007)

The previous map series depicted the dispersal of both *Streptopelia* species across the colonised landscape in relation to landuse and climate: Discussion now moves to an investigation of the *Spatial Statistics* related to these populations, including: '*Standard Distance*' ( ); *Directional Distribution* ( ); *Mean Centre* (★) and *Central Feature* (☆) (Map 6.27 and Map 6.28) (refer to explanations in Chapter 3, page 56). The vastly different distributions of the two species populations are clearly discernible in these maps.

Standard Distance, the measure of the extent features are concentrated or dispersed, shows that Spotted Dove is the lesser by far. The features are localised and concentrated within metropolitan confines. In contrast, that of the Laughing Dove is vast and extends way beyond the greater metropolitan area; north and south along the coast and deep inland into rural areas synonymous with the growth of cereal crops.

Differences in the *Directional Distribution* statistic, a measure of directional trends identified in the features are also evident. Once again that of the Spotted Dove extends to a lesser distance, as it trends north, north-east; and south, south-west along expanding urban corridors. Whereas the directional spread of the Laughing Dove covers more distance and trends north-west, into urban coastal areas; and inland to the south-east, into areas cultivated for dryland agriculture.

In terms of the remaining statistics, the *Mean Centre* (centre of concentration for a set of features); and the *Central Feature* (the most centrally located feature), the Spotted Dove features sit almost on top of each other and are located close to the metropolitan release site in South Perth. Whereas the Laughing Dove features are spaced apart, with the *Central Feature* situated near the South Perth release site, but the *Mean Centre* positioned some distance away in the south-east: close to major transport routes, including the Albany and Brookton Highways, as well as the Great Southern freight rail network.

This concludes discussion on *Spatial Statistics* associated with the dispersal of the species. It also winds up discussion comparisons in their dispersal patterns subsequent to their release into the study area.

The final section of the chapter examines the dispersion of the species. Dispersion, as previously explained, differs from dispersal as it is not a measure of range as such, but refers to "the internal distribution pattern of individuals within a population" (Emmel, 1973, p. 64). Dispersion is mostly influenced by resource availability within the range, although predator avoidance is also a factor.

6.7.13 Dispersion of Spotted Dove and Laughing Dove within the Study Area:

The final aspect of the data analysis relates to patterns in the dispersion of the species. Whilst dispersal within a population does not always change the overall distribution of a species, it does influence patterns of abundance and dissemination within the range i.e. the dispersion of the population. The act of dispersing "allows birds to respond rapidly to local conditions" (Newton, 2003, p. 472). It assists them in relocating away from unfavourable habitat such as areas that have little food or are over-crowded. It may also help them sustain a presence in an area where the population is threatened, by promoting reoccupation of previously vacated habitat. It is a critical ecological process that influences population distribution and density.

> …while populations of birds and other animals are ultimately limited by the availability of food, this limit, with resultant overpopulation and starvation, is not normally reached in nature, because dispersion through behaviour keeps numbers near to the 'optimum' and below the level where 'overfishing' might develop (Lack, 1966, p. 300).

Although most species of birds are highly mobile, the assumption they can disperse to anywhere, even within their geographical range, is not correct. Many birds display 'site fidelity' (refer page 27), a "faithfulness to a site or group" (Greenwood, 1980, p. 1140). Individuals may have initially dispersed away from the natal site, but once having bred in a location, will return to it and reuse it subsequently and breed there over successive years. Although many bird species are philopatric, usually "only a proportion of individuals of any species is faithful to one locality" (Greenwood, 1980, p. 1140). The remainder generally disperse through being forced out of an area, or depart because of environmental conditions.

The concept is not to be confused with 'natal philopatry' (refer page 27), whereby "offspring remain at their natal area and share the home range or territory with their parents" (Goodenough *et al.*, 2010, p. 234) (and which differs from 'natal dispersal', the movement of the species between the social group or natal area where breeding first occurs). Behavioural restraints such as these can ultimately limit dispersal distances, and cause clustering within distributions.

Both the Spotted Dove and Laughing Dove are sedentary species and usually establish a territory and stay close to it. The Laughing Dove, in particular, displays strong site-fidelity, an individual having been recorded in several instances returning to a capture site after being relocated. Despite the relocation site being some distance away and the return trip to the capture site taking days, or even weeks to complete.

The tools used to investigate patterns of dispersion within the distributions are Moran's *Index* and *Average Nearest Neighbour* analysis. Detailed explanations of these analyses are given in Chapter 3, pages 58-59).

Table 6.12: Moran's **Index:** ***Streptopelia*** **Doves – Excludes Breeding**
(Source: The Present Study)

Comparison of Spotted Dove and Laughing Dove: Moran's I index (Excludes Breeding)					
Era/Group	Moran's I	**Expected**	**Variance**	***Z - Score***	**Description**
Spotted Dove_Era_A	0.11047	-0.01333	0.00293	2.24394	Moderately Clustered
Laughing Dove_Era_A	0.25519	-0.00752	0.00036	13.89303	Highly Clustered
Spotted Dove_Era_B	0.56355	-0.00201	0.00545	7.65823	Highly Clustered
Laughing Dove_Era_B	0.44369	-0.00064	0.00298	8.13561	Highly Clustered
Spotted Dove_Era_C	0.26188	-0.00030	0.00010	26.54999	Highly Clustered
Laughing Dove_Era_C	0.44221	-0.00015	0.00007	53.70653	Highly Clustered

The results using Moran's Index analysis of data related to the distributions of the Spotted Dove and Laughing Dove (Table 6.12) are very similar. The only classification that varies between the species (excluding breeding), is for the Spotted Dove in Era A, 1898-1953. The Moran's I score is less than half that of the Laughing Dove, and is classified as being only 'Moderately Clustered'. Whereas, the Laughing Dove populations score high enough to be classified 'Highly Clustered'. Differences in the *Z-Score* are also significant; with the Laughing Dove score six times that of the Spotted Dove, indicating similarity between features.

By Era B, 1954-1980, the internal distribution of the Spotted Dove has changed, to 'Highly Clustered', with the Moran's I score approximately five times greater than that calculated for the preceding phase. The corresponding *Z-Score* has also increased to more than three times that calculated for Era A. For the Laughing Dove, by Era B, the Moran's *I* score has almost doubled since the preceding era; which indicates intensified clustering of the population; yet the *Z-Score* has reduced, hinting at a declining similarity between the features as the population moves beyond urban areas and into the interior.

By Era C, the Spotted Dove Moran's I score has been reduced from the previous era; but is still high enough for the population to remain 'Highly Clustered'. The corresponding *Z-Score* has increased to almost four times that of the preceding area indicating increasing similarity between the surrounding features. This is in line with the range contraction of the species as it intensifies it metropolitan populations.

In terms of the Laughing Dove during Era B, the internal distribution of the species remained 'Highly Clustered'; whilst the Moran's Index score was reduced marginally (0.00148): of note is the jump in the '*Z-Score* '; an increase of close to 400% from the Era A score. This indicates intensifying similarity between features. By this stage the species are heavily concentrated throughout the metropolitan area as well as dispersed widely across dryland agricultural areas.

Table 6.13: Moran's **Index: *Streptopelia* Doves – Breeding Data Only**
(Source: The Present Study)

Comparison of Spotted Dove and Laughing Dove: Moran's I ndex (Breeding Only)					
Era/Group	Moran's I	**Expected**	**Variance**	***Z- Score***	**Description**
Spotted Dove_Breeding_Era_A	0.09094	-0.12500	0.01032	2.12552	Moderately Clustered
Laughing Dove_Breeding_Era_A	-0.05586	-0.14286	0.02989	0.05033	Random
Spotted Dove_Breeding_Era_B	0.79910	-0.02564	0.43958	1.24394	Random
Laughing Dove_Breeding_Era_B	0.26754	-0.00562	0.01923	1.96987	Moderately Clustered
Spotted Dove_Breeding_Era_C	0.37737	-0.02174	0.00252	7.95382	Highly Clustered
Laughing Dove_Breeding_Era_C	0.18261	-0.0051	0.00021	13.02634	Highly Clustered

However, the analyses vary in relation to breeding (Table 6.13). For the Spotted Dove, Era A, breeding populations are classified as 'Moderately Clustered', the same as the overall population. The moderate clustering probably arises from the concentration of breeding records within the rural north-east sector.

The 'Random' classification for the Laughing Dove, which is determined by the negative Moran's I score, is different to the classification of its overall distribution. The much lower *Z-Score* than that calculated for the Spotted Dove reflects the occurrences of breeding for this species being more widely spaced. To reiterate, in nature, random distributions are considered rare, as natural resources are rarely distributed at random, but are associated with patterns inherent in the physical geography of the region. Predator avoidance is also a relevant factor. In relation to the present study it may be that low data availability influenced outcomes.

By Era B, 1954-1980, the classifications have become reversed, with breeding occurrences of the Spotted Dove classified as 'Random' and those of the Laughing Dove changed to 'Moderately Clustered'. Breeding by the Spotted Dove, whilst mainly around the metropolitan area, also occurred in country areas, which presumably influenced the result.

In relation to the Laughing Dove, a positive Moran's I is recorded, although it is quite low. The corresponding *Z-Score* is also low which indicates dissimilarity between features. During this period, whilst the majority of breeding is occurring within metropolitan confines, it is also occurring in rural areas.

Whilst these 'Random' classifications arise from the spatial data, it may be that site selection was driven by ecological suitability for breeding. The premise of Lack (1966) is that populations generally do not disperse randomly, and particularly seldom in relation to breeding. He asserts that a species will relocate to "a type of habitat less favourable except in being less crowded" (1966, p. 299); this suggests site selection is based upon site suitability rather than a random response to conditions.

For Era C, 1981-2007, breeding for both the Spotted Dove and the Laughing Dove are classified as 'Highly Clustered'. Although the Moran's I score for the Spotted Dove is double that of the Laughing Dove, which indicates clustering of breeding occurrences are greater fort his species. This situation is reversed in relation *Z-Score* with the Laughing Dove indicating a stronger similarity between features. This is probably linked to the overall distribution contracting westward, and it not extending as far eastward as it did in Era B.

Discussion now moves to results of the *Average Nearest Neighbour* analysis, a measure of the average distance from each feature to its nearest neighbour. The tool assumes all features measured are free to locate anywhere within the study area i.e. no barriers; and that all features are independent of one another. It also most appropriate when the study area is fixed. All these assumptions are met by the present study.

The statistic which provides the best 'spatial snapshot' is the *Observed Mean Distance* calculation. If the computations are less than the average calculated for a hypothetical random distribution, the features are classified as 'Clustered'; if they are greater than, then they are classified as 'Dispersed'.

The results of *Average Nearest Neighbour* analysis however produce identical classes for both species, although the magnitude varies between each for all eras (Table 6.14). The highest *Observed Mean Distance* score is that of the Spotted Dove for Era A which indicates that at this stage in the invasion process the species exhibited the greatest extent of spread and had the most expansive distances between records. This is probably due to the species being recorded in the north-east sector, close to the rural release site of Yatheroo.

Table 6.14: Average Nearest Neighbour: *Streptopelia* Doves – Excludes Breeding
(Source: The Present Study)

Comparison of Spotted Dove and Laughing Dove: *Average Nearest Neighbour* (Excludes Breeding)					
Era/Group	***Observed Mean Distance***	**Expected Mean Distance**	**Nearest Neighbour Ratio**	***Z-Score***	**Distribution**
Spotted Dove_Era_A	0.131422	0.270378	0.486069	-8.571217	Clustered
Laughing Dove_Era_A	0.081529	0.222122	0.368538	-13.773671	Clustered
Spotted Dove_Era_B	0.011492	0.095533	0.156186	-36.024018	Clustered
Laughing Dove_Era_B	0.010058	0.793860	0.126695	-65.838864	Clustered
Spotted Dove_Era_C	0.001048	0.016048	0.065301	-103.635261	Clustered
Laughing Dove_Era_C	0.002432	0.042625	0.057059	-148.283290	Clustered

However, as colonisation was not sustained the figure is reduced substantially in Era B, and again in Era C. The figures are consistent with the graphic depictions of the chronological map series: Era A, wide-ranging dispersal away from the metropolitan release site and a presence in rural localities in proximity to release sites. In Era B, a declining presence in rural areas and intensified metropolitan populations; in Era C, steady decline in rural populations and denser concentrations of metropolitan populations.

The lower *Observed Mean Distance* score in Era A for the Laughing Dove than the Spotted Dove is probably due to differences in dispersal patterns. At this stage the dispersal of the Laughing Dove took a linear trajectory along transport vectors into the interior; as well as stepping-stone spread into other rural sites. Colonisation was sustained by long-term breeding and permanent populations were established in many rural localities. The reduction in the calculation for subsequent eras reflects the increasing density of urban populations.

Table 6.15: Average Nearest Neighbour: *Streptopelia* Doves – Breeding Data Only
(Source: The Present Study)

Comparison of Spotted Dove and Laughing Dove: *Average Nearest Neighbour* (Breeding Only)					
Era/Group	***Observed Mean Distance***	**Expected Mean Distance**	**Nearest Neighbour Ratio**	***Z-Score***	**Distribution**
Spotted Dove_ Breeding_Era_A	0.707607	0.060451	11.705511	61.441181	Dispersed
Laughing Dove_ Breeding_Era_A	0.660605	0.388998	1.698220	3.778055	Dispersed
Spotted Dove_ Breeding_Era_B	0.035675	0.077618	0.459621	-6.538218	Clustered
Laughing Dove_ Breeding_Era_B	0.064172	0.210164	0.305341	-17.779884	Clustered
Spotted Dove_ Breeding_Era_C	0.014548	0.025493	0.570657	-5.630979	Clustered
Laughing Dove_ Breeding_Era_C	0.033177	0.220425	0.150513	-22.809772	Clustered

In terms of breeding (Table 6.15) the *Observed Mean Distance* statistic is highest during Era A; with breeding occurrences for both species classified as 'Dispersed'. This is probably due to the release of both species in the metropolitan area as well as several rural sites that span hundreds of kilometres. By Era B, the classifications for both species have changed to 'Clustered' and remain so for Era C. In relation to the Spotted Dove this is probably due to breeding incidences increasing in urban areas. For the Laughing Dove, whilst breeding intensified in the metropolitan area, it was also widespread across rural areas.

Intensified clustering for both *Streptopelia* species is evident in the steady reduction of the *Observed Mean Distance* statistic. This indicates both species are displaying site-specific habitat selection for breeding. It may also indicate a degree of philopatry in the species. However the changes could be a response to territory sizes reducing from increased competition for space and resources as the overall distribution contracts in response to changing ecological conditions.

For the Spotted Dove, the greatest reduction in *Observed Mean Distance* occurs between Era A, and Era B: with the Era B calculation almost twenty times less than that for Era A. This indicates that not only are breeding occurrences becoming more concentrated, but the spatial buffer maintained between breeding pairs is reducing. A further reduction in Era C, demonstrates the trend is enduring.

For the Laughing Dove in Era A, the *Observed Mean Distance* in relation to breeding is only slightly lower than that of the Spotted Dove (<0.05). This indicates that both species are utilising resources throughout the study area to sustain colonisation. By Era B the figure has reduced to about a tenth that of Era A; with a further decrease in Era C. This indicates that like the Spotted Dove, breeding occurrences are concentrating and the space between breeding pairs is reducing. The outcomes are in line with the overall range contraction by the speciesAs with the findings from the examination of the patterns of dispersal of these two species; despite sharing similar physical attributes and ecological profiles, differences in the way the populations are dispersed are also evident.

Whether the steady reduction in the *Observed Mean Distance* calculations for both species throughout each era correlates with a reduction in territory size is not measured. It simply implies that the amount of space between each record is decreasing; a result of the intensification of metropolitan populations and contraction of rural sightings for the Laughing Dove.

In consideration of what functional 'Territory Type' (refer Chapter 2, page 31) of territory each species maintains, both probably confirm to 'Type E' birds (as per Hinde, 1956), which includes pigeons (Columbidae). Birds in this category sometimes roost socially, and will defend a roost site from birds of a different type. They will defend their sleeping position against those of the same species when roosting socially. Both birds are sedentary and do not seasonally disperse. Nor do either maintain a permanent territory year round, but are opportunistic in meeting their ecological requirements.

They will move about in search of food, and probably only reduce the area covered if food sources are abundant (Stenger, 1958) to avoid an energy deficit arising from defending too large a territory when all required resources are close-by. They may also reduce the area foraged as a response to over-crowding when competition for space and resources is high.

If the assumption of Schoener (1968b) is correct, that "territory size was directly proportional to the bird's body weight, i.e. larger species defended larger areas" (Perrins & Birkhead, 1983, p. 12), then the suggestion is that the Spotted Dove may maintain a larger territory than the Laughing Dove. However, as the terms of reference for the present study did not extend to an investigation of this, the supposition is purely speculative.

This concludes discussion on the dispersion of the Spotted Dove and the Laughing Dove. Concluding remarks reviewing the previous discussion will now be presented.

6.8 Conclusion:

The Spotted Dove and the Laughing Dove have become common features of the birdlife of the Southwest region, especially around the metropolitan area and on some offshore islands. The Laughing Dove is also widespread and is present in many country areas.

The extent of colonisation success by both species in the study area is not surprising given that they are common and widely dispersed in the places from which they originate. Both species have also colonised numerous other countries and regions within Australia.

Whilst both species are sedentary and do not display seasonal movements, they do not maintain a year round territory either. Rather, they are opportunistic in meeting feeding and breeding requirements. They will forage in parks, gardens, poultry-yards and wasteland, as well as cattle feedlots, and grain storage silos. They also forage in built up areas and will nest in artificial structures. Despite not maintaining a permanent territory, both species, like other Columbidae species are likely to defend their roost from others of a different kind, and against their own kind to maintain their position within the roost if nesting socially.

Both display attributes that are the mark of successful biological invaders, as per the five 'rules' set down by Brown (1989) (Refer Chapter 2, 18). However, the first rule relates only to the dispersal of the Laughing Dove across the 'Wheatbelt', an area of dryland agriculture, in so much as per 'Rule 1', that isolated environments with a low diversity of native species tend to be differentially susceptible to invasion. The Wheatbelt, which represents the largest portion of the geographic range of the Laughing Dove, was extensively cleared for cropping (of up to 90% of its native vegetation (Beeston et al., 2001).

Habitat loss of this magnitude had a major impact on regional biodiversity; which, despite the cessation of broadscale clearing in the 1980s, remains vulnerable due to other "threatening process including salinity...weed invasion, altered fire regimes, feral animals and climate change" (Wheeler, Beecham, Walshe, Penter, & Kietzmann, 2007, p. 267).

The four other rules set by Brown however, apply to both species: In regard to 'Rule 2', they are both species native to continents and to extensive, non-isolated habitats within continents. In relation to 'Rule 3', both species come from regions that share similarities in the physical environment between the source and target areas.

Also, as per 'Rule 4', both have filled a niche not utilised by other native species; and in terms of 'Rule 5', both inhabit disturbed environments and have a history of close association with humans and settling man-modified habitats in their places of origin.

Other than invasibility of the Wheatbelt environment, the spread of the Laughing Dove was aided by the availability of food, sourced from the produce grown, stored and transported. Also, farms and homesteads had water supplies; which removed the 'moisture barrier' that may have prohibited the movement of the species into the interior. The species also utilised transport routes to cut through 'bush barriers' as well as forage along for grain spilled during transit.

However, following the initial incursion of the Laughing Dove into the Wheatbelt in Era A, it experienced a marked range contraction in Era B as a result of the phasing out of bagged grain marketing and introduction of bulk grain handling and transport. Populations became concentrated around towns that had storage silos and those that supported sizeable human settlements to provide for their ecological needs. Metropolitan populations however continued to intensify throughout these periods.

Whilst, in Era A, both the Spotted Dove and Laughing Dove breached the scarp and pushed east, north-east beyond the Darling Ranges; by Era B, the Spotted Dove populations had contracted to mainly within urban confines. This may have been a spatial response by the species to avoid having to maintain too larger territory to sustain itself; or be an indication it was less tolerant of the more natural bushland environment inland, away from the urbanised coast belt.

Throughout Era B and Era C the Spotted Dove populations grew increasingly concentrated in the metropolitan area. The few sightings beyond were close to rural release sites. Sightings in rural areas continued to decline in Era C, by which time the distribution of the species had become completely localised to an area of the central Swan Coastal Plain, extending from Yanchep to Mandurah, bounded by the ranges.

However, moisture cannot be the only alleviating factor prohibiting the spread of the species into country areas (other than the Wheatbelt); as neither have colonised the higher rainfall areas of the south-west sector that support extensive areas of wet sclerophyll forest. The forests contain a dense understorey that is hard to penetrate for these predominantly ground dwelling, seed foraging species.

Besides being physically challenging, the bush may also contain noxious plants, of the *Gastrolobium* R. Br., genus, belonging to one of the largest legume genera of the region that form a major component of the understorey in bushland areas of the study area. Another area in which they are common that has not been settled by either of the *Streptopelia* species is patches of remnant Geraldton Sandplains vegetation along the north of the Swan Coastal Plain.

Other of these botanical barriers, these bushland also harbours other threats; introduced predators, such as feral cats and foxes; as well as a winged predator: the Laughing Kookaburra. This iconic Australian species was also an orchestrated introduction into the study area, and is the focus of the final case study.

7 ICONIC INVADER: LAUGHING KOOKABURRA

(Dacelo novaeguineae)

7.1 Nomenclature and Taxonomy:

The name ‘Kookaburra’ derives from ‘Gugubarra’, as given by the Wiradjuri people of New South Wales (Gran & Rudder, 2005). It is also known by other names which reference its call and social habits (refer ‘Vocalisation and Social Behaviour’). The multiplication of names is not limited to the vernacular however, with its scientific nomenclature also a subject of “controversy and confusion” (Mees, 1977, p. 35).

Misconception surrounding the species dates back to its inclusion in a collection of New Guinea avifauna compiled by Sonnerat (1776); hence the scientific name *novaeguineae*. His works were later found to be flawed and included the “intentional falsification” (Mees, 1977, p. 35) of the presence of the Kookaburra in New Guinea. The specimen he claimed as his own was later identified as coming to him from naturalist Joseph Banks from his explorations in 1770 (Lysaught, 1956).

As a result of this fabrication, the misnomer was written into the latter works of Buffon (1780) and Daubenton (1765-81). Then in 1783 “almost simultaneously, Hermann and Boddaert provided scientific names according to the Linnaean system of nomenclature” (Mees, 1977, p. 35). Based on the work of Daubenton, Hermann ascribed *Alcedo novae Guinea*, and Boddaert, *Alcedo gigas*. That of Hermann fell into disuse until Stresemann (1920) petitioned that it had priority, thus igniting the more recent debate (Lysaught, 1957).

The *Integrated Taxonomic Information System* places it in Order, Coraciiformes; Family, Alcedinidae (river kingfishers); Subfamily Halcyoninae (tree kingfishers); Genus *Dacelo* (Leach *et al*., 1814); Species, *Dacelo novaeguineae* (Hermann, 1783) with further classification into Subspecies *D. n. novaeguineae* (Hermann, 1783), and *D.n. minor* (Robinson, 1900) in identifying distributional clines (ITIS, 2013). The taxonomic classifications of Sibley and Ahlquist (1990), and Fry, Fry and Harris (1992) however differ from this and are challenged by Moyle (2006) based on analyses conducted of the molecular phylogeny of Alcedinidae.

The nomenclature adopted for the present study is *Dacelo novaeguineae* as suggested by Christidis and Boles (1994); *Dacelo* being an anagram of *Alcedo* to avoid confusion with another Genus of kingfisher. This applies to the species hereafter referred to as Laughing Kookaburra, or simply, Kookaburra.

7.2 Physical Characteristics:

The Laughing Kookaburra is the largest kingfisher in the world. It varies in size however, probably due to differences between the different parts of its geographic distribution. Females hatch larger than males and remain so for life (Table 7.1).

Table 7.1: Variations in dimensions in geographical distributions
(Source: Keast, 1957)

Laughing Kookaburra: Variations in dimensions in geographical distributions			
Tail Length mm	**Wing Length mm**	**Distribution**	**Source**
154-162	213-225	Melbourne	(Keast, 1957)
152-162	215-230	Sydney	(Keast, 1957)
147-154	209-220	Cairns	(Keast, 1957)
148	200	Cooktown	(Keast, 1957)
145-155	192-210	Cape York	(Keast, 1957)

The vernacular name of the species makes reference to its vocalising, a series of calls that culminate in a raucous cackle. Other than its unusual socialising and vocalisation, the species has also evolved other exceptional features adapted to optimise hatchling survival and hunting prowess. The plumage however, is plain, (Plate 7.1) with the wing and upper-parts dark brown, displaying a touch of blue on the shoulder and a white patch at the wing base.

The head is light brown with dark streaks on the crown, a dark brown ear patch and line across the eye. A broad white nuchal band is visible behind the head; the tail is brown, banded with black and the under-parts white. The eyes are grey-brown and legs pale brown. The beak is black on top and white on the bottom (Pizzey & Knight, 1997; Schodde & Tidemann, 2003; Serventy & Whittell, 1948).

Plate 7.1:Laughing Kookaburra, largest kingfisher in the world
(Tate, 2008g)

A study by Parry (1973) found some variation in plumage according to both age and sex: fledglings, whilst similar to adults have a mottled and darker forehead and shorter bill and tail. The lower mandible is black not bone but by three months this has lightened and the bill and tail have reached full length. There is no moult between fledgling and juvenile phases, and juveniles grow to resemble adult females. Variations between the sexes include colouration of the rump, with most males displaying a touch of blue Plate 7.2). The hue of which can vary "from a vivid azure easily seen by the naked eye to a tinge discernible only when the bird was in the hand" (Parry, 1973, p. 73). Also, females are mainly brown, with a slight blue tinge, and males display white feathers above the eye, whereas females are buff above the eye.

The feet also have an unusual feature, syndactyly. Like other Kingfishers they have three forward pointing toes and one backward pointing toe, with the middle toe the longest. The three forward pointing toes are fused at the base for one-third of their length, to facilitate the capture and grasping of prey (Eastman, 1970; Higgins, 1999). However, unlike birds of prey their feet are not overtly strong.

Other 'hunter' adaptations include its large beak that is almost the same length as the head, to aid grasping prey, and a bony ridge on the back of the skull that attaches to strong neck muscles to thrash prey to subdue or kill it (Parry, 1970). In hatchlings the beak is hooked for the purpose of siblicide i.e. predation amongst nestlings (Woodall, 2001), a practice common in the species (detailed in 'Breeding', page 240).

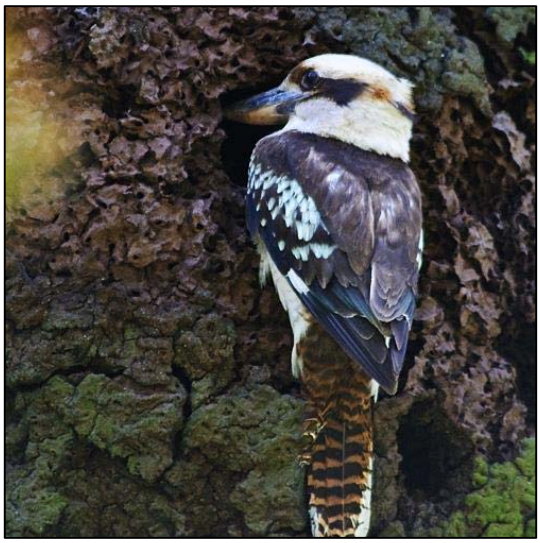


Plate 7.2: Laughing Kookaburra, male, displaying blue on rump
(Paris, 2006)

The eyesight of the Laughing Kookaburra is also exceptional, being made up of two areas that are rich in 'fovea' receptors. Within the eye, vision is first honed by monocular fovea. Then with the rotation of the head, secondary receptors engage to form binocular vision to allow for greater detection of the position and movement of prey (Moroney & Pettigrew, 1987). The keen sight of the bird is most evident when it suddenly sweeps down from a high perch, to secure prey.

Another unusual biological characteristic of the Laughing Kookaburra is that it is "the only member of the Alcedinidae known to employ heterothermy" (Cooper, Kortner, Brigham, & Geiser, 2008, p. 4). The feature enables the species to reduce and regulate body temperature to below normothermic temperature by falling into a daily torpor (Cooper *et al.*, 2008). It is a condition mainly limited to mammals (Geiser, Körtner, Maddocks, & Brigham, 2006) and in avian species is usually found in small birds that inhabit harsh habitats with unpredictable climates or have "diets that are temporally and spatially patchy" (Cooper *et al.*, 2008, p. 2).

Whilst its roosting time is comparable with other diurnal bird species - approximately 12 hours per night - unlike most birds the Kookaburra is able to significantly reduce its body temperature, by about 9.1°C (Figure 7.1). Another physiological feature is that it can lower its basal metabolic rate to conserve energy (Buttemer, Nicol, & Sharman, 2003): a feature that may be linked to huddling behaviour when at roost.

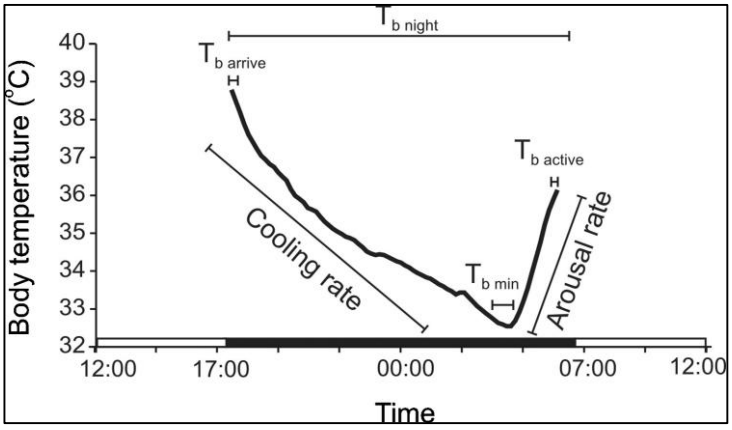


Figure 7.1: Body temperature of Laughing Kookaburra during nocturnal rest phase
Time between sunset and sunrise indicated by black bar along x-axis; thin bars indicate calculation of various temperature variables; T b night = mean nocturnal temperature; T b min = minimum body temperature, T b arrive – body temperature when arriving at the roost site; T b active – body temperature when leaving the roost site (Source: Cooper *et al.*, 2008, p. 2).

Prior to departing from the roost the species increases its body temperature by "endogenous metabolic heat production" (Cooper *et al.*, 2008, p. 5) (Figure 7.2) reducing its dependence on solar radiation to rewarm. As it does not have to passively rewarm it can depart the roost prior to sunrise, and return after sunset, extending foraging time. The feature is advantageous in seeking out ectothermic prey, such as snakes and lizards, which have to bask in warm sunshine to reach high activity levels. It adjusts roost departure times on inclement days, probably as the energy advantage is reduced somewhat due to the scarcity of prey.

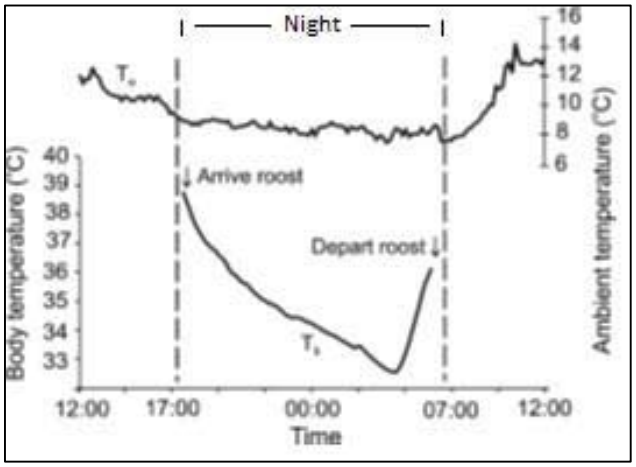


Figure 7.2: Body temperature of Laughing Kookaburra
Displaying rewarming prior to leaving roost)
(Rewarming occurs prior to departing the roost, and prior to sunrise and increasing ambient temperature, and occurs as a result of endogenous heat production, not passive rewarming. The vertical dashed lines represent sunset and sunrise (Source: Cooper *et al.*, 2008, p. 4).

The feature appears to be limited to free-ranging birds, with no captive Laughing Kookaburras displaying the same temperature fluctuations (Geiser *et al.*, 2006). This has been attributed to several factors: (i) the food supply is anticipated and constant; (ii) energy conservation is less important; and (iii) species may not feel secure enough to fall into the vulnerable, highly unresponsive state of torpor.

However, this efficient predator is also prone to disease, with a study by Reece (2007) identifying several naturally occurring neoplasms in free-ranging Laughing Kookaburras. These include intra-abdominal Lipomas and Cholangiomas; a malign tube-like tumour in the epithelium of the bile duct (Latimer, 1994).

This concludes discussion on the physical attributes of the bird. Discussion now moves to examination of the vocalisation of the species, one of its most defining features. The calls, though, are much more than just sound, they are inextricably linked to the social structure of the group and the behaviour of individuals within the group.

7.3 Vocalisation and Social Behaviour:

The Laughing Kookaburra is known by many other names (Table 7.2). Most reference its distinctive call or habit of calling in the pre-dawn (Keast, 1985), a trait linked to its unusual physiology, a rarity amongst birds, in that it is heterothermic (refer above). But despite this physiological advantage, variation in diet and year-round territory maintenance can cause energetic stress on free-living kookaburras (Schodde & Tidemann, 1997).

Table 7.2: Laughing Kookaburra – vernacular names
(Source: Encyclopedia of Life, 2013)

Laughing Kookaburra – Vernacular names *(Dacelo novaeguineae)* In Avibase - IOC World Bird Names List	
Alarm Bird	Jacky
Australian Laughing Jackass	Johnny
Breakfast Bird	Kooka
Brown Kingfisher	Kookaburra
Bushman's Clock	Laughing Jack
Giant Kingfisher	Laughing Jackass
Great Brown Kingfisher	Laughing John
Ha Ha Duck	Laughing Johnny
Ha Ha Pigeon	Settler's Clock
Jack	Shepherd's Clock
Jackass	Woop Woop Pigeon

Whilst acting as a wake-up call for its neighbours, "the true function of the familiar cacophony is to advertise the territory of this bold bird" (Schodde & Tidemann, 1997, p. 345) as it maintains a permanent territory all year. The territory may be occupied by a "single mated pair or by a family consisting of three or more members" (Parry, 1973, p. 84); intruders are not tolerated. The defence of territory promotes recognition of boundaries amongst members of the same species. Such is evidenced by a report in Parry (1970) of a kookaburra that would not cross a boundary invisible to humans into an adjacent territory to retrieve food tossed there.

Territorial defence is a group activity whereby a 'defence' perch is chosen from which to guard the territory; usually juxtaposed to the perch occupied by the group guarding the abutting territory (Plate 7.3). First an individual from one group alights to a tree within its territory before returning to the defence perch. The procedure is then repeated by others in the group; each passing one another in a skilful aerial display (Plate 7.4). The group then pauses to allow the display to be repeated by the birds occupying the adjacent territory. Sessions may last as long as half an hour (Higgins, 1999).

Plate 7.3: Laughing Kookaburra, song chorus for territorial defence
(Bergh, 2013a)

Plate 7.4: Aerial flight display for territorial defence
(Tate, 2008h)

Territory defence is closely linked to vocalisation by the species. Detailed descriptions of the laugh-chorus and it relation to social behaviour were first given in Parry (1968, 1970) and Eastman (1970). Later, Parry (1972, 1973) undertook scientific investigations of the Kookaburra repertoire, identifying six chorus types. These were expanded by Reyer and Schmidl (1988), with a seventh category added, but that still incorporated the elements earlier identified by Parry.

The chorus types identified are described as (i) *Song or Laugh Song*, full-throated 'ha ha ha'; (ii) *Koooa*, short, guttural sound; (iii) *Rolling*, the repetition of identical syllables that precedes Laugh Song; (iv) *Gurgle*, like rolling but with longer pause between syllables. Parry subsumes the 'rolling' and the 'gurgle' as *chuckle* but Reyer and Schmidl (1988, p. 150-151)

distinguish them; *Gogo*, as distinct syllables, either 'go go' or 'who who' (as per Parry); *Cackle*, loud repetitive sound similar to 'ha ha'; and *Squawk*, a hoarse monosyllabic sound, low in pitch (Parry, 1968, 1972).

The study by Reyer and Schmidl also measured diurnal patterns of the song, and identified two peaks: Between 04.30 hours and 05.30 hours preceding sunrise, confirming the cultural lore about the species habit of rising before the sun; and another between17.30 hours and 18.30 hours, at sunset. The more members of the group gathered, the more frequent the songs. In between these peaks, chorus-song was rare, restricted to the identification of territorial boundaries or if there was dispute amongst a mated male and the nest helpers (1988, p. 155).

The study also confirmed that when singing, Kookaburras stay in close proximity to each other, or at least maintain visual contact. Nor is communal perching confined to singing, but also occurs during preening, foraging and resting. Within the group, breeding pairs remain close-by each other, and usually follow each other from perch-to-perch as well as sing together.

A later study by Woodall (2001) identified only five elements to the chorus song, whereas Baker (2004), in a study of Western Australian Kookaburras, like Parry, identified six 'syllables', each graded with particular modal forms. The group chorus arises, says Baker, from simultaneous vocalisation by several birds and is completed by one of two 'introductory sets' of syllable repetitions by a single bird. The same study also compared the mid-chorus vocalisations of several groups. It found "group-specific vocal signature information in the laugh-song" (2004, p. 21). The differences between the groups, and similarities within groups were credited to either 'imitated learning', or 'heritable variation'.

There is however some disagreement about the function of the chorus-song. The interpretations of Parry (1968, 1972) have been challenged by Reyer and Schmidl (1988) who do not concur fully with the four functions of song proposed by Parry: (i) territorial defence and declaration; (ii) localisation of group members and co-ordinating activities; (iii) strengthening the social bond; and (iv) relief of nervous tension. They regard the last point as "a motivational constraint rather than a real function" (1988, p. 157).

The evidence given by Parry for the territorial function includes the fact that (a) the song is usually uttered at or near the territorial boundary accompanied by flight defence display; (b) that birds from neighbouring territories usually respond with laugh-song; and (c) that the peak of intensity corresponds to an adjustment of territory (1968, p. 34). Whilst Reyer and Schmidl support and expand on the territorial function of song, they reject Parry's analyses of intra-group functions suggesting that it an aggressive behaviour related to mate-guarding and establishing and maintaining a dominance hierarchy within the group. In terms of the link between laughing and inter-group aggression they found it most evident in pairs caught up in a border dispute with intruding neighbours.

Also, the number of roost dawn songs did not relate to the size of the group, but rather, the number of neighbours. As the frequency of songs did not increase with the number of neighbours present, it is a probably a mechanism for scaring off vagrant intruders. The threat of early morning intruders is also attributed to the intensity of the dawn-song, as the group may be vulnerable as a result of overnight mortality (1988, p. 158).

The relationship between laughing and intra-group aggression is related to the correlation between the number of intra-group attacks and the number of daytime songs involving helpers, as well as the understanding that attacks on helpers can be provoked by a song (real and recorded). Daytime singing by helpers probably signals a challenge to the dominant male's breeding status. The response to the songs by members within the group helps establish and maintain the hierarchy of the group. Singing between male and female breeders arises from the tendency of the male to not only protect his own female, but attract other females, and the females "opposing tendency to monopolise the parental investment of her mate (1988, p. 158-159).

The term ‘helpers’ referred to previously relates to multiple offspring of previous clutches that stay with the group, and are characteristic of the social structure and hierarchy of the species. A helper may also be referred to as an ‘auxiliary’ (as per Skutch, 1935, 1961) or ‘supernumerary’ (as per Rowley, 1965). The terms extend to include all non-breeding birds that remain with the parents within the territory, throughout the year. They are integral to territory defence, the incubation of eggs and care of nestlings and fledglings.

The hierarchy within the family group is determined by age and sex: The adult breeding male is dominant over all male auxilaries , whilst all older auxilaries are dominant over younger siblings. Breeding females are dominant over female auxilaries. Fledglings are suborginate to all group members of the same sex.The subordinate roles of auxilaries within the hierachy probably plays a part in supressing the urge to breed (Myers, 1996).

Juveniles that survive the first year function as auxiliaries and assist the parents in rearing the next brood, and sometimes the following brood. After which they will generally depart the area just prior to the next breeding. The auxiliary role is not dictated by sex, with both males and females carrying out duties. Whilst sexual maturity can be reached in one year, some birds retain their non-breeding status for up to four years. This explains the sometimes large family groups (Parry, 1973).

Other than assisting with the maintenance of the young within the family group, auxiliaries play another important role. They act “as a reserve pool of experienced non-breeding adults” (1973, p. 87) for non-family groups, filling vacancies arising from the death or disappearance of a member of a neighbouring group (a vacancy created by the departure of an individual to breed elsewhere).

However, a study by Legge and Cockburn (2000) found that within groups the turnover of dominant birds is low, as the dominant pair rarely changes, resulting in few opportunities for auxiliaries to fill a dominant vacancy. Generally there are more female vacancies, as the mortality rate for females is higher. Higher female mortality is linked to reversed sexual dimorphism associated to females being heavier and suffering more from food shortages and harsh environmental conditions.

When a dominant does disappear, helpers do not evict the other dominant to make way for another, unrelated bird to take up the position. The main method adapted by an auxiliary to obtain dominant status is to form a new pair, with a male from one group pairing with a female from another group, without bringing helpers. Once paired, they establish a new territory by interacting with neighbouring groups. New pairs are often formed between helpers of neighbouring natal territories already familiar with each other (Legge & Cockburn, 2000).

Kookaburras also engage in play. Such as the repeated throwing of a stone against a branch to mimic prey-killing (Watson, 1992). Within the group, agonistic play, such as sparring assists in establishing dominance between members of the group.

The sparring pair comes together, grasp bills, twist their heads and bodies vigorously and use the wings for balance. The game ends when one flies away (Parry, 1973).

This concludes examination of the Vocalisation and Social Behaviour of the species. The investigation now moves into exploring habitat and food preferences.

7.4 Habitat and Food:

In its native range, the Laughing Kookaburra "is an inhabitant of the sclerophyll and savannah woodlands" (Keast, 1957, p. 64). Whilst its range extends into drier areas, it is susceptible to heat and drought and so maintains mainly coastal populations. It is found along watercourses and in farmlands, orchards, parks and gardens (Pizzey & Knight, 1997). It prefers mature trees, often *Eucalyptus* of a sufficient height from which to scour for food, competitors or predators. Observations made in the course of the present study identified White Gum (*E. wandoo*); Marri (*E. calophylla*, later renamed *Corymbia calophylla*) and Jam Tree (*Acacia acuminata*) as frequently occupied sentinel trees.

Territory sizes vary, but are usually quite large (range 16-224 ha) (Legge & Cockburn, 2000). The area must contain an area of clearing, trees for roosting, sufficient nest holes and posts for displays of territorial defence, usually along each territory boundary. Running water is not an essential feature, as long as water is accessible (Parry, 1973).

In urban areas, however, the species has adapted to foraging in parks and gardens. During the course of the research several anecdotes were related about the propensity of the species to pluck fish from ornamental ponds; and snatch a sausage from the barbecue! Perhaps the elongated symmetry of the titbit makes it looks like a worm or reptile!

Several survey respondents listed Kookaburra as a regular visitor to their gardens. The birds come to be fed by residents and grow accustomed to being close to people. One group has attended a property in Scarborough for several years and feeds close to the house and its occupants (Personal Communication, Simon Cornelius, 17 March 2010) (Plate 7.5 and Plate 7.6). Another group has attended a property in Wattle Grove for several years. The dominant male of this group is accustomed to hopping into an empty hanging-basket to retrieve food (Personal Communication, Raelene Francis, 31 May 2009) (Plate 7.7).

However, habitual feeding by people can result in problems for the birds and residents. Sometimes a bird will tap and fly at windows to demand food, or attack their reflection as they think it is another Kookaburra competing for the resource. This can result in property damage or injury to the bird (Temby, 2004). Birds can also become overweight (Holland, 2010) which reduces their mobility and makes them vulnerable to predators.

Plate 7.5: Family group feeding at house in Scarborough
(The place where they are feeding is only 3.0 metres from the rear door of the house)
(Cornelius, 2009a)

Plate 7.6: Juvenile at Scarborough property
(The perch is about 2.0 metres from the rear door of the house, next to an outdoor dining table)
(Cornelius, 2009b)

Plate 7.7: Retrieving foods from hanging basket
(The hanging basket is 3.5 metres from the rear door of the house, adjacent to a pool area)
(Francis, 2010)

The diet consists mostly of invertebrates: insects, spiders, millipedes, centipedes and worms, as well as Jewel beetles, Buprestidae (*Stigmodera macularia*; *S. variabilis*; *S. grandis*; *Melobasis* sp); Longicorn beetles, Cerambycidae, (*Penthea vermicularia*; *Coptopterus* sp; Stag beetles, Scarabaeidae (*Lamprima latreillei*); Flower-chafers, Cetonidae (*Cachochroa gymnopleura*; *C. variabilis*) and Weevils, Curculionidae (*Chrysolophus spectabilis*) (Hindwood, 1947). A detailed dietary summary is given in Barker and Vestjens (1989) (Part 1: Table 7.3 and Part 2: Table 7.4Table 7.4).

The main prey sought, says Legge (2004), are animals that live near to, or on the ground. Any variation in what is taken is attributable to what is available within the habitat. Although belonging to Alcedinidae (river kingfishers) the species is not piscivorous and takes few aquatic species (other than pond fish) although these include crayfish, yabbies, land crab, tailor, redfin and glass perch (Barker & Vestjens, 1989). It has also been observed taking freshwater mussels (Campbell, 1901). Occasionally small reptiles, such as lizards and snakes are taken (Plate 7.8 and Plate 7.9) as well as frogs (Plate 7.10). Small rodents, including House Mouse *(Mus musculus*) (Lepschi, 1997) are also predated upon (Plate 7.11**),** as well as rats (Plate 7.12). When other prey is short, small birds are also hunted (Plate 7.13).

The extent to which the species hunts lizards and snakes is unclear, although it is known to take snakes of up to one metre long (Ralph & Ralph, 1973; Woodall, 2001), including Tiger Snake (*Notechis scutatus*) (Vestjens, 1977). Whilst "it owes a lot of the affection it has been given to the fact that it is a snake killer" (Douglas, 1980, p. 24), this perception may be somewhat misguided as it is kills mostly "harmless small varieties and even legless lizards…native creatures and normal inhabitants of the environment" (1980, p. 24). There are those says Chisholm (1969, p. 122), who believe the bird "sufficiently resolute to attack a snake of any reasonable size", whilst others "argue that he rarely assails snakes at all" and never "one more than about eighteen inches [45cm] in length". The truth he says, "lies somewhere between".

Snake hunting is sometimes a cooperative effort, says Chisholm, with one bird seizing the prey, flying high and dropping it, with the process repeated by others until the snake is killed. Another method sees one bird seize the snake by the neck, and another by the tail, before shaking it to death. An adaptation of this has been seen to include up to four birds attacking the snake at once (Ryan, 1919).

The instinct to grasp the neck of the snake to avoid its fangs however presents another dilemma for the bird, as the power of its beak and neck are not equalled by its feet. As a consequence the poorly secured prey sometimes coils around the bird, rendering it helpless (Campbell, 1901). This is probably why it is sometimes compelled to adopt the 'dropping' method to kill its prey. Prey is rarely carried far in flight as it can over-burden the bird and cause it to crash to the ground.

Whilst its status as a snake killer is ambiguous, they are known to be predators of Blue-tongued Skink, or 'bobtail', *Trachydosaurus rugosus* (reclassified as *Tiliqua rugosa*) (Barker & Vestjens, 1989) of which there are three subspecies endemic to Western Australia: *T.r. rugosa*; V.*r. konowi* (Rottnest Island skink) and *T.r. alarra* (Shark Bay skink). A study of predation of Scincidae by Kookaburra identified predation upon mainly "small and medium-sized rather than large lizards in the field" (Blomberg & Shine, 2000, p. 484). Nest remains contained skeletal vertebrae bones (20.39%) and limb bones (29.81%), as well as mammalian remains, although most were of saurian origin, mainly smaller sized specimens.

However, this could be due to larger prey being eaten at the point of capture to avoid transporting it, or because larger specimens are more aware of the dangers of predation making them harder to catch. However the results should not be seen as an indication that large prey are not taken as Kookaburras "are very large and powerful predators, and easily capable of overpowering even the largest skink" (Blomberg & Shine, 2000, p. 488).

Plate 7.8: Predation on a lizard
(Ross, 2011)

Plate 7.9:Predation on a snake
(Raoul, 2004)

Table 7.3:Main food types of the Laughing Kookaburra: Part 1
(Phyla: Mollusca, Annelida and Arthropoda) (Barker & Vestjens, 1989)

FOOD OF LAUGHING KOOKABURRA: PART I (Barker & Vestjens, 1989)									
Phylum	**Sub-phylum**	**Class**	**Sub-class**	**Order**	**Sub-order**	**Family**	**Genus**	**Species**	**Common name**
Mollusca									
		Gastropoda							snails
									slugs
								Bulinus sp.	freshwater snail
								Helix aspersa	
								H.Cunninghami	land snail
								Helix sp.	
Annelida									
			Oligochaeta						
						Lumbricidae			earthworms
Arthropoda									
		Diplopoda							millipedes
		Chilopoda							centipedes
		Insecta							
				Odonata					insects
					Zygoptera				damselflies
				Mantodea					mantids
				Dermaptera					
								Labidura riparia	
				Orthopetera					
						Tettigoniidae			
						Gryllidae			crickets
									black crickets
								Teleogryllus commodus	
						Gryllotalpidae			
								Gryllotalpa sp.	mole cricket
						Acrididae			
								Acrida conica	
				Hemipetera					
						Cicadidae			cicada
						Lygaeidae			
						Pentatomidae			
				Coleoptera					beetles
						Dytiscidae			
								Homeodytes scutellaris	adults and larvae
						Passalidae			
						Scarabaeidae			
							Scarabaeinae	*Orthophagus* sp.	
							Melolothinae		
							Rutelinae	*Anoplognathus* sp.	
						Cleridae			
						Chrysomelidae			
								Paropsis sp.	
						Curculionidae			weevils
							Amycterinae		
				Lepidoptera					
									caterpillars
						Noctuidae			
								Spodoptera sp.	armyworms
				Hymenoptera					
						Formicidae			
									ants
								Camponotus sp.	
								Iridomyrmex sp.	
	Crustacea								crayfish
									land crab
		Malacostraca							yabbies
								Cherax destructor	
		Arachnida							spiders
								Missulena sp.	

Table 7.4: Main food types of the Laughing Kookaburra: Part 2
(Phylum: Chordata)

FOOD OF LAUGHING KOOKABURRA: PART II (Barker & Vestjens, 1989)									
Phylum	**Sub-phylum**	**Class**	**Sub-class**	**Order**	**Sub-order**	**Family**	**Genus**	**Species**	**Common name**
Chordata									
		Pisces							
						Pomatomidae			
								Pomatomus saltator	tailor
						Percidae			
								Perca fluviatilis	redfin perch
						Centropomidae			
								Velambassis jacksoniensis	
		Amphibia							
						Myobatrachidae			
								Limnodynastes tasmaniensis	
		Reptilia							lizards
									snakes
						Scincidae			
								Trachydosaurus rugosus	
		Aves							
						Anatidae			
									domestic ducklings
						Phasianidae			
								Coturnix ypsilophorus	
								Gallus gallus	young chickens
							Orthonychidae		
								Cinclosoma punctatum	juveniles
						Corvidae			
								Corvus sp.	crow
		Mammalia							
				Rodentia					rodents
						Muridae			mice
									rats
				Lagomorpha					
						Leporidae			
								Oryctolagus cuniculus cuniculus	

Plate 7.10:Predation on a frog
(Taylor, 2009)

Plate 7.11: Predation on a mouse
(Montgomery, 2005)

Plate 7.12: Predation on a rat
(Bergh, 2013c)

Plate 7.13: Predation on a bird
(Bergh, 2013b)

As listed previously, other than its predation of reptiles, the species also preys upon frogs. Within the Southwest study area there are more than 20 species of frogs; some which are unique to the region. It has been approximated that up to 10% of Australian frog species have declined (Tyler, 1991); and within the last 15 years a few have declined so significantly they are considered 'rare' and others are presumed extinct (Blaustein & Wake, 1990; Main, 1990).

These events have been linked to the indirect effects of anthropogenic changes (Beebe, 1977; Carey, 1993); including the arrival of introduced predators, such as Kookaburra, into their native range. A review by Main (1990) of the influence of land clearing, agricultural activity and associated salination of waterways in the Wheatbelt, found a reduction of the geographic range of Western Spotted Frog (*Heleioporus albopunctatus*) linked to these factors.

Another species, White-bellied Frog, is 'Critically Endangered', with only limited distributions remaining along the edge of the Southwest region. Both areas are densely inhabited by the Laughing Kookaburra, effectively adding increased predation risk by the species to an already existing biodiversity crisis.

Other than its predation of reptiles and frogs, Kookaburras are also known to prey on other birds. A study by Scott, Piper and Catterall (2006) attributed 68% of nest predation to birds, identifying larger generalist species such as *Corvus* (ravens), *Gymnorhina* (magpies) and *Cracticus* (butcherbirds) as those most often responsible. However, Kookaburra is also listed amongst frequent avian predators (2006, p. 119).

Predation of Aves by Kookaburra is considered to be mainly of chickens, ducklings, quail and corvids (Barker & Vestjens, 1989; Frith & Frith, 1997), although Orthonychidae, a genus of small birds are also listed amongst foods of the Laughing Kookaburra. However a report by A.G. Campbell (1926, pages 312-313) disputes this supposition.

In it he lists several other bird species captured by the Kookaburra, including "the wily sparrow", "a small nestling from the mud nest" of a Magpie Lark (*Grallina cyanoleuca*), and, a Speckled Warbler (*Chthonicola sagittata*) nestling, if not for the accuracy of a hastily thrown hat. Nearby, he says, "were the nests of a Yellow Robin (*Eopsaltria australis*), with newly hatched young, a Scarlet Robin (*Petroica multicolor*) sitting, and a Blue Wren (*Malurus cyaneus*) with eggs" (1926, p. 313). The following day, the Speckled Warblers were annihilated, with the nest looking "forcibly opened". Within that week, "the contents of the other nests disappeared in the same way".

Later observations recall a Kookaburra in flight with a Silvereye (*Zosterops lateralis*) nest, and a nestful of week-old Cuckoos disappearing after 'Jack' saw "from his wayside perch the little birds busily feeding the nestling" (1926, p. 313). The nest was later found "torn open and rifled" beneath a tree. Later a Shrike-thrush was observed scolding away a Kookaburra, but close to the time of hatching, first one egg, then another disappeared "and the bird deserted; then the last egg went", whilst the Kookaburra remained. He believes the Kookaburra presents a threat that "is serious for the little birds".

To conclude the chapter on a lighter note, is a story relating the experience of a fellow who kept finding strange objects dropped into an isolated section of his bush garden; and having items go missing and being relocated to inaccessible areas of the block. The mystery the occurrences was solved when the culprit, a Laughing Kookaburra, was identified after being observed with its 'prey' in its mouth. It was seen busily thrashing, the 'animal', one of two ornamental frogs decorating the garden. It absconded with the trinket, only to return several days later in an attempt to capture the other (France, 2007, p.10).

This concludes discussion on the habitat and food preferences of the Laughing Kookaburra. Discussion now moves to the breeding habits of the species.

7.5 Breeding:

The main breeding period for the Laughing Kookaburra commences in September and extends into December (Campbell, 1901; Parry, 1973); and January (Legge, 2000b, 2002). Results derived from the present study substantiate this (Figure 7.3) with September recording the second highest rate of breeding and October the highest; with an incremental decline in breeding frequencies between November to January. The sharp fall in breeding events between February-August indicates a biological response by the species to poor environmental conditions that would inhibit breeding success.

The period of breeding coincides with optimal food availability, with laying ceasing whilst food is still plentiful (Lack, 1966). For, he reasons, if laying eggs continued when the food supply was diminishing it would not be abundant for the young. He suggests the laying - period is an evolved response to ensure the young can be reared successfully. The period of breeding for Laughing Kookaburra coincides with the 'Austral Spring' (Legge, 2000b, 2002); a time when food is abundant.

Pairs mate for many years, if not life, or until one dies or disappears. Most often only a single brood is raised each season (Legge, 2000b, 2002), sometimes two, in September and November (Campbell, 1901). The clutch size can vary between two to four eggs, with the median calculated at two (2.1) (Parry, 1973). There are variations, with North (1909) reporting a clutch of five and Parry (1973) reporting two clutches of one, of which neither hatched. There is no significant variation in clutch size between those laid early, or late in the season.

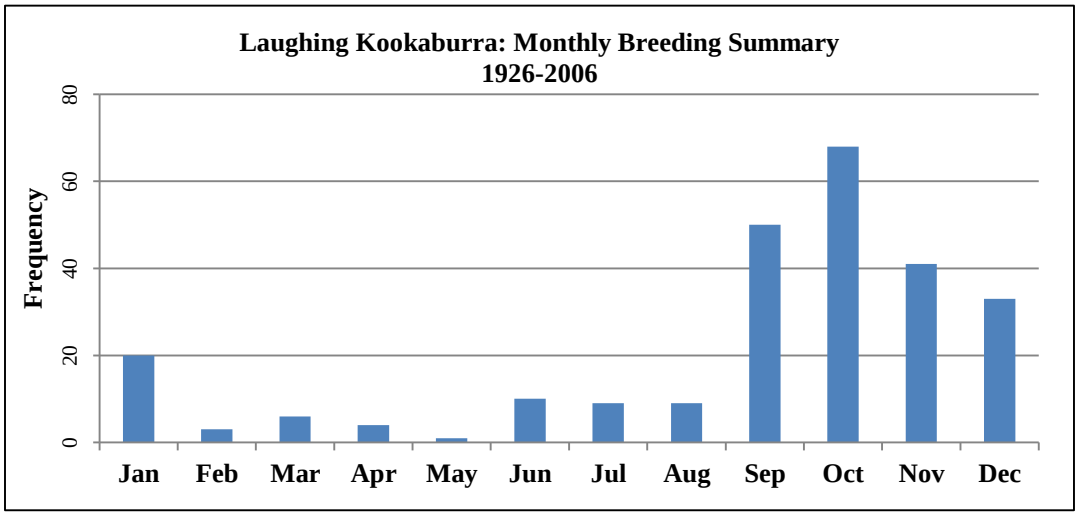


Figure 7.3: Monthly Breeding Summary, 1926-2006
(Source: The Present Study)

For the nest a level tree hollow to about 20 metres high is preferred. However the species also utilise alternate sites large enough to accommodate an adult, such as a "hole in a bank, tree-termite nest, haystack or wall" (Pizzey & Knight, 1997, p. 316).

Unusual nest sites reported include the centre of a Staghorn Fern (*Platycerium alcicorne*) (Campbell, 1901); in the end of stacked lucerne hay; in a hollow in the side of an earth cutting; in a hollowed out ledge on cliff face of a disused quarry; on the top of stone pillar verandah support; and in a pigeon loft and a hole in a building in the centre of a city (Sydney) (Bourke, 1941; Hindwood, 1942). The examples given here are consistent with those listed in Parry (1973) (Table 7.5).

Table 7.5: Nest site locations
(Adapted from Parry, 1973)

Laughing Kookaburra: Nest site locations						
Location/type	**Forest**	**Woodland**	**<6 m**	**7-9 m**	**10-15 m**	**16-20m**
Eucalyptus spp						
Mountain Grey Gum	X		2	3	6	6
Peppermint Gum	X			1		
Blue Gum	X				1	
Red Gum		X				
Unidentified Gum	X		1	3	3	
Unidentified Gum		X	3	1		
Other trees						
Angophora			1			
Unidentified tree		X		2		
Other						
Termite's nest		X	1	2		
Haystack		X	3			
City-building			1	1		
Nest-box			2			
Cliff-face			3			
Burnt stump			1			

The structure of the nest though is specific: a flat floored chamber that "opens directly to entrance hole, through which chicks excrete" (Schodde & Tidemann, 2003, p. 345). Expulsion of faeces through muscular action allows it to be expelled up to 82cm from the hole. The fluid consistency and lack of mucilage in the faeces is an evolved adaptation by the species to aid the process (Thomson, 1934).

No nesting materials are used and eggs are laid on the floor. Old nests if "not taken over by other birds, possums or bees" (Parry, 1973, p. 89) are reused and new nest sites are excavated by both the male and female. Photographs showing a Kookaburra attending a nest hole (at Yellagonga Regional Park) are shown below (Plate 7.14; Plate 7.15and Plate 7.16).

Plate 7.14:Bird entering a nest hole (Yellagonga Regional Park)
(Tate, 2008i)

Plate 7.15:Leaving a nest hole
(Tate, 2008j)

Plate 7.16:Taking flight from nest hole
(Tate, 2008k)

The ‘roundish’ eggs are sharply contracted at one end, and measure about 46mm x 36mm (Schodde & Tidemann, 2003, p. 345). The surface of the egg is shiny and the shell finely textured(Campbell, 1901). Eggs are laid over a 1-4 day interval. Incubation of the eggs commences prior to the clutch being complete and lasts about 24 days (range 22.22 to 25.23 days: mean 23.22 days) (Parry, 1973). Incubation of the eggs during laying is restricted to the breeding female (Legge, 2000b), but is later shared by both male and female helpers, sometimes for prolonged periods of time.

In families with multiple auxiliaries caring days are alternated. Older helpers sit longest and attend the nest more regularly (Parry, 1973). The male breeder performs the bulk of parental care, from incubation to food provision (Legge & Cockburn, 2000). The eggs hatch asynchronously at 2 hour to 72 hour intervals (Legge, 2000a), giving the first hatched a considerable weight advantage over later hatched nestlings (between 7-135% more) (Legge, 2000b). The first hatched is usually fed more than later hatchlings. Nestlings hatch blind and naked and with a hook at the end of the beak (Plate 7.17and Plate 7.18).

Nestlings are fully feathered between 30-39 days; but remain in the nest from 33–39 days. Distinct stages of nestling growth were identified by Parry (1973, p. 93):

1-7 days:	Completely naked and blind;
7-10 days:	Slits on eyelids form;
7-11 days:	Pin feathers on body, wings emerge;
10-13 days:	Eye-slits begin to open;
10-15 days:	Pin feathers grow from 0.5mm to 3.0mm, begin to show pattern of plumage;
14-17 days:	Eyes fully open;
17-22 days:	Quills on body burst;
22-27 days:	Quills on head and flight-feathers burst;
27-30 days:	Quills round cere burst.

When multiple fledges have been reared they rarely leave the nest together. Usually departures are spaced a day apart, with the eldest departing first, though not always. Departure is pre-empted by the fledges first sitting near the edge of the hole for several hours “stretching but not flapping the wings” (1973, p. 94). Adults occupy a nearby nest-perch and sound out intermittent feeding calls as well as retrieve and eat small food items, but rarely feed the nestlings during this period. Fledged juveniles remain nutritionally dependent until about eight weeks of age.

Several factors have been found to influence the extent of nest success and the sex of nestlings: Larger group size does not improve nest success, as when there are more helpers the breeders reduce their contribution to compensate for that of the helpers. Larger groups also experience increased egg loss arising from incubation by more attendants. Larger groups also usually had more female than male helpers.

Female helpers have been identified as reducing nest success because they interrupt breeding attempts. The breeding female views other females competitively and spends time driving them away. Also, there is a discrepancy between the extent of help provided by male and female helpers, as "males incubate eggs and provision nestlings at a higher rate the females" (Legge, 2000a, p. 721). Female contributions are sometimes overvalued to the detriment of overall cooperative effort.

Groups with more female helpers tend to produce a male biased clutch and fledgling sex ratio; whereas groups without female helpers (unassisted pairs or male only helpers) produced a female biased clutch and fledgling sex ratio. In terms of the sex in relation to the order of hatching; two-thirds of first hatched are male; two-thirds of second hatched are female; with the sex ratio of third hatched nestlings even (Legge, Heinsohn, Double, Griffiths, & Cockburn, 2001). First hatched males have a weight gain advantage over later hatched females that hatch larger in size.

Whilst losses at egg stage are attributed to infertility, breakage, predation and tossing; during nestling phase, the main cause of deaths is brood reduction (Legge, 2000b), of which the major contributors are starvation and siblicide (Plate 7.19). The 'siblicide syndrome' has been well documented (Legge, 2000a, 2000b, 2002; Nathan, Legge, & Cockburn, 2001). Results from one study (Legge, 2000a), found that of all eggs laid in a season more than half produced a fledgling, with losses greatest during the nestling phase (whilst only 16.5% of eggs failed to hatch; 32.1% of hatchlings failed to fledge). Siblicide usually occurs against the third (or fourth) hatched and weakest chick within four days of hatching. Whilst the surviving hatchlings do not utilise the dead chick as food, an adult brooding chicks has been seen to (Nathan *et al.*, 2001).

Further mortality occurs between when the young fledge to when they are nutritionally independent, from predation, disease, abandonment and accident. Brood reduction was the highest cause of mortality (54.4%). In broods where at least two eggs hatched, 41.7% experienced sibling aggression (29.2%) or starvation (19%), some nests experienced both. (Legge, 2000a). Detailed accounts of siblicide amongst Kookaburras are given in Legge (2000b, 2002, 2004) and Nathan *et al* (2001).

Plate 7.17:Kookaburra nestlings recently hatched (and egg)
(Australian Broadcasting Commission, 2005c)

Plate 7.18:Kookaburra nestling displaying hooked beak
(Australian Broadcasting Commission, 2005b)

Plate 7.19: Kookaburras nestling in act of siblicide
(Australian Broadcasting Commission, 2005a)

7.6 Optimal Invader:

It is possible to view the Laughing Kookaburra as a 'whole organism' whose physiology is closely integrated with its ecological and social behaviour. Its ability to self-warm (heterothermy) and enter torpor (reduce body temperature) to conserve energy gives it an energy advantage over other species. It is an efficient hunter aided by binocular vision, a well-developed bill and strong neck and wing beats. Hunting is sometimes done cooperatively to offset a lack of foot strength resulting from syndactyly, a feature common amongst Kingfishers. Its produces complex vocalisations to aid territorial defence, mate guarding and establish intra-group hierarchy. Groups form around a breeding pair with the dominant male instigating territorial defence by intense vocalising and aerial displays. The vocalisations and displays are copied by others in the group.

They live cooperatively in family groups which include the breeding pair and non-breeding adults and juveniles from prior broods (Plate 7.20). Nomad individuals are not tolerated (Parry, 1973) and new pairings usually arise from unpaired adults of neighbouring groups coming together. Sex allocation in nestlings is influenced by the majority sex of auxiliaries, with more males hatching from clutches tended by mainly female helpers, and more females hatching in clutches tended by unassisted pairs or groups with mainly male helpers. Obligate siblicide limits death of nestlings by starvation; and maintains brood fitness. The young also engage in play, like sparring to aid in establishing dominance; and mimic prey-killing in preparation for hunting.

Plate 7.20: Family group hierarchy
(Dominant male far right, hierarchy descending to left)
(Blogspot, 2013)

In accordance with Darwinian principles, the species evolved adaptability allows it to optimise its environment and produce robust and efficient offspring. Its proficiencies have made it a highly successful invader capable of colonising a range of habitat types, which within the study area includes forest conservation areas, remnant bushland, and urban parks and gardens. It has also adapted to living in close proximity to humans.

The diagram below (Figure 7.4) shows the relationship between the physical habitat settled by the species and the ways in which its physiological adaptions allow it to optimise the use of territorial resources. Its highly developed song is capable of complex vocalisations to undertake territorial defence. The song is not only a tool for this purpose, but an aid to inter-group and intra-group identification and mate guarding during breeding.

Territorial defence, which is year round, is reinforced by aerial displays from a defence perch within the territory. The flight order is designated by a dominance hierarchy within the group that is led by a dominant male belonging to a breeding pair. Groups are made up of mature (male and female) non-breeders (two to three year old prior young) and juveniles (fledged young from previous season). These auxiliaries assist with brood rearing, with duties ranging from incubation to feeding. Once fledged the juveniles are engaged in play to establish dominance, and develop prey killing skills.

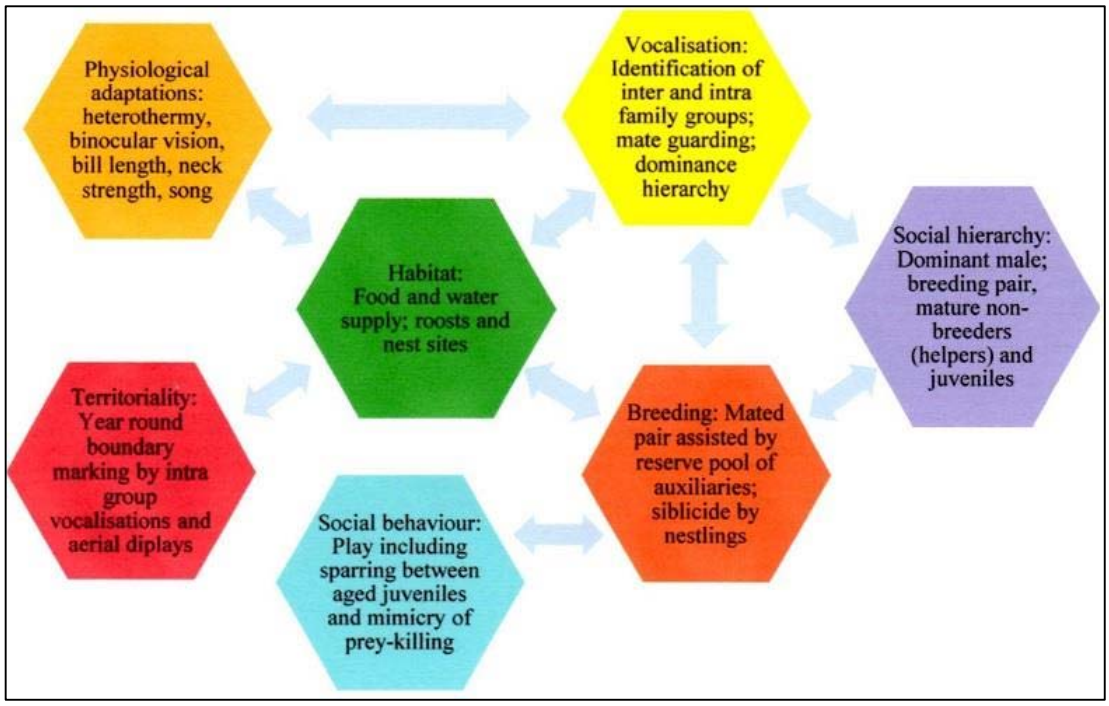


Figure 7.4: Laughing Kookaburra - Rhizoid relationship
(Between habitat, physiology and behaviour)
(Source: The Present Study)

7.7 Status of the Species in other Australian States and Territories:

The historical distribution of the species within Australia extends across eastern Australia from Cape York Peninsula, Queensland; south and west to the southern Eyre Peninsula, South Australia. It was introduced into Western Australia, as well as Kangaroo, Flinders and Waterhouse Islands and Tasmania (Legge, 2004).

In his text on introduced birds of the world, Long (1981) reports that the species was introduced Kangaroo Island in January 1926 "when two pairs were liberated" (1981, p. 288); and references several other records to substantiate this: Lashmar (1935); Wheeler (1960); Condon (1968) and Abbott (1974). In closing Long concludes "the species is probably still present there" (1981, p. 288). This assumption has been substantiated based on records of the *Eremaea Birds* database (2013) which list sightings of the species there for 1980, 2000, 2011 and 2012.

In relation to Flinders Island, Long (1981) references Condon (1968), a text which details birds of South Australia. However, notes by Green (1969) on the Kookaburra in relation to 'Flinders Island', are in relation to the island within the Furneaux Group, near Tasmania, where several Kookaburras "were introduced in the centre of the island about 1940" (1969, p. 13); and have since "bred up and spread but have not yet reached the extreme north or south".

However there is speculation that these birds "may have colonised from nearby Waterhouse Island even earlier" (Legge, 2004, p. 24) as the Launceston Society, as well as private individuals began releasing Kookaburras on Waterhouse Island and Tasmania's north coast from 1902 onwards (Legge, 2004). It has colonised widely and is well established across most of Tasmania.

The deliberate introductions of the species into these locations enabled Laughing Kookaburra to overcome two major distributional barriers that had previously maintained clear geographic demarcation of the various forms: Bass Straight was removed as a barrier to the southward spread of the species; and the Nullarbor Plain, which limited the westward spread of the species was overcome. Having once occupied the entire southern regions "when "forest birds occurred from east to west" (Keast, 1957, p. 71), the species have, since their artificial arrival into the Southwest forests, not only survived, but thrived. It is this journey, to which we now turn.

7.8 Status of the Species Outside of Australia:

The Laughing Kookaburra has been introduced to few places outside of Australia despite "its personable nature and its reputation as a useful predator of vermin" (Legge, 2004, p. 23). A proposal to import them was mooted by the United Kingdom Acclimatisation Society in 1860, but was never actioned. A later attempt by the Victorian [Acclimatisation] Society in 1875 to send birds to Britain also never came to fruition. Reputedly single birds made it over, with one living in the London Zoological Society gardens; and another at a private home in Sussex.

According to Thomson (1922), the first Kookaburras introduced to New Zealand were released at Kawau in the early 1860s, by Governor Sir George Grey. Further introductions were made by the Canterbury Society (1864); Otago Society (1866 and 1869); Nelson Society (1867), Auckland Society (1868) and Wellington Society (1879). In the text, Thomson mentions a few 'Laughing Jackasses' being present in the wild east of Auckland, but the claim was later disputed by Oliver (1930), who maintains that only the Kawau release produced a permanent population and any others present on the mainland originated from there. The species was reported by Long (1981, p. 289) to be "common on the coast opposite that island in the late 1920s.

Later Oliver (1955) reported that the species had become established around the North Auckland area, from Whangarei to the Waitakere Ranges, as well as Kawau Island. A decade on, Falla, Sibson and Turbot (1966) lists "a small but fairly stable population surviving along the western shore of Hauraki Gulf" (Long, 1981, p. 289). The current population is estimated at 300-500 birds, within about 2500km^2 taking in Kawau Island and parts of the adjacent mainland (Perrott, 2008).

In 2008 Perrott proposed research to investigate the breeding biology of the species in relation to its limited distribution. The proposed research also seeks to address concerns about predation by Kookaburra on native New Zealand birds and endangered geckos species. It has also flagged investigation into a form of lice that is parasitising the population.

There was an attempt prior to 1926 to introduce it to Fiji (Wood & Wetmore, 1926); and it is mentioned later in relation to Viti Levu by visiting ornithologists (Blackburn, 1971). However it failed to establish a permanent population there.

No other evidence was found of any other instances of introduction of wild populations of the Laughing Kookaburra globally, although some are kept in zoos of the world. The translocation of the species within Australia will now be examined.

7.9 Data Analysis:

The following summaries are based on the presentation of spatial and temporal data prepared expressly for the present study. Although every effort was made to ensure the integrity of the data were not compromised, and they are as true and correct as possible, a timely reminder that it is subject to limitations is proffered. The analyses that follow are based solely upon the sightings recorded and cannot claim to be a definitive summary.

A map series: Era A (1898 – 1953), *Introduction, Death or Captivity*; Era B (1954-1980), *Establish or Fail*; Era C (1981-2007), *Spread or Remain Local*; All Eras (1898-2007), Chronology of Spread each display changes in the dispersal of the selected species over time set within the context of the 'Invasion Process Model' adapted from Lockwood *et al* (2007). A '*Spatial Statistics*' map summarises the data in spatial expressions including: '*Standard Distance*', '*Directional Distribution*', '*Mean Centre*', and '*Central Feature*'.

Another map series depicts the dispersal of the species in relation to climate and landuse features of the study area. Doing so provides a means of investigating the extent to which these factors influence site selection and distributions. Spatial autocorrelation analyses were also conducted to determine patterns in the dispersion of the species i.e. the patterns of spread within the distributions.

The discussion related to these maps and analyses aims to 'tell the story' of the species arrival to, colonisation of, and spread throughout the study area. This commences with the circumstances as to how the species arrived to the study area.

7.9.1 Transport:

The translocation of the Laughing Kookaburra from the eastern States into the study area was also orchestrated by the Director of the Perth Zoological Gardens, Ernest Le Souëf, in collaboration with the Acclimatisation Committee of Western Australia (ACWA). The liberations occurred subsequent to 1896 (Serventy, 1948) or 1897 (Long, 1988); with hundreds of the birds imported into the State between1897-1912, and possibly even later. Although initially liberated from the Zoological Gardens, they were eventually "distributed in every direction" (Le Souëf, 1912).

In a report on ACWA activities, dated October 1897, mention is made that the "laughing jackass, or giant kingfisher, has been successfully introduced into the Swan and Southern districts" (1897a). Although, it was proving difficult to acquire enough birds to meet the demand for them; with one consignment of 20 "coming in very slowly" (ACWA, 1897b); and requests for more, by W.E. Learoyd, on behalf of the Committee, were blocked by legalities. New South Wales authorities met the request with consternation, on the basis that "the laughing jackass was absolutely protected" and the supply of 100-200 birds needed high level government approval. Similarly, in Victoria, special permission was required to take the birds; and they were expensive, with Learoyd lamenting "it would not be in my opinion judicious to purchase any at 8s per pair (8 shillings [or 80 cents] per pair)" (ACWA, 1897b).

Enquiries into procuring birds from South Australia met slightly less resistance; for although not a protected species, and costing somewhat less, birds could only be taken at certain times of the year (outside of breeding season). However, the demand for such a large number could not immediately be met as capturing them was a lengthy process. Once consigned, and en route, the long boat trip sometimes exacted a heavy toll, especially upon young birds (ACWA, 1897b).

However, despite these setbacks many were eventually sourced, including 30 "very fine specimens" (Anon, 1898, p. 4) shipped from Victoria with the intent to "turn them loose to propagate" in their new surroundings. Months later, a similar sized group was "liberated in various localities" (ACWA, 1898). Within the year, the success of the free birds was evident, which encouraged the Committee to continue:

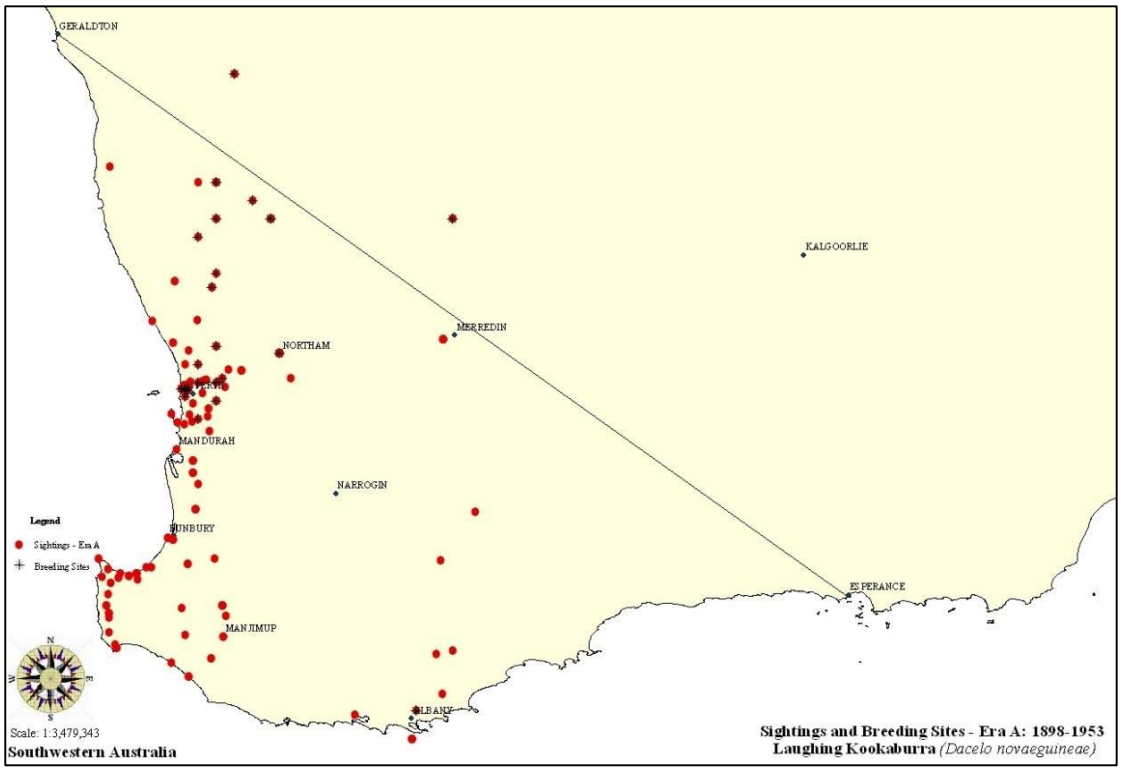
> …introducing more of these interesting and useful birds which not only relieve the monotony of the bush silence by their laughing note, but are also good friends to the agriculturalist, as they devour, besides snakes, numbers of noxious insects (ACWA, 1899, p. 60).

A report by Le Souëf, dated 1902, lists the Kookaburra as "breeding freely and doing excellent work with regard to insect pests and young snakes" (ACWA, 1902, p. 8). By the next decade it is "in great demand amongst our settlers", with many "desirous of seeing and hearing them about their homesteads". Demand was again outstripping supply, with a note being made that " none has been released during the past year on account of the difficulty experienced in obtaining them from Victoria" (ACWA, 1916, p. 4). Rather, it was hoped that locally bred birds can be used to meet demand, as, already, in some localities, such as Warren and Hamel, there are more to be seen than "ever seen in the same time in any part of the Eastern States".

However by the next decade, the popularity of the species, and the wisdom of bringing them into the State, were being questioned. With the Perth Museum Keeper of Biology, W.B. Alexander, raising concerns that the good done by the species in controlling pests may be "outweighed by the numbers of insectivorous birds which they destroy as nestlings" (1919, p. 8). Debate as to the costs and benefits wrought by the species upon the local environment has continued across ensuing decades (ACWA, 1937a; 1937b; Le Souëf, 1928) and remains a contentious issue.

Discussion now turns to the dynamics of dispersal of the species following colonisation, as interpreted by the *Invasion Process Model* (Lockwood *et al.*, 2007).

7.9.2 Era A: 1898 – 1953: Introduction, Death or Captivity:



Map 7.1: Dispersal of Laughing Kookaburra, Era A: 1898 – 1953
(Including Breeding)

Sightings of the Laughing Kookaburra Era A (•) 1898-1953, *Introduction, Death or Captivity* (Map 7.1) are already widespread throughout urban areas and extend into rural areas especially along the coast and inland. The sightings in rural areas are probably attributable to the various releases in country areas and not linked to birds released from the Zoological Gardens and other urban localities.

There were repeated releases between 1896/97-1912 (possibly as late as 1914, refer ACWA, 1916, p. 4), at sites in South Perth, Serpentine, Guildford, York, Gingin, Pinjarra, Canning and along the Blackwood River (Jenkins, 1977). Other independent introductions may have also occurred, with reports of the birds around Mullewa *circa* 1896, as well as at Irwin and Mingenew districts that were thought unlikely to have "derived from the Perth releases" (Jenkins, 1959, p. 206).

Within a few years of arriving, as well as adapting well to the natural habitat, the species had grown less wary of humans; with some at a Bayswater farm were "so tame that they take worms from a ploughman's hand" (Kendall, 1903). The birds were also making use of the 'treasures' turned up by the plough, and getting under-foot of the horses.

By the 1920s the species were well established between the coast and the Darling Ranges (Kingsmill, 1920), and by the 1930s was recorded as common between Mandurah and Bunbury (Serventy, 1930). As the 1930s drew to a close, the species was also well established south of the Bunbury district (Whitlock, 1939).

However, its arrival into some areas, like Bridgetown, was not welcomed by all, with Whittell (1932), describing it as "Very numerous and a bird I dislike for its habit of preying on young, small birds" (p.187). Whilst such criticism might sometimes be dismissed, in this case the author is highly credible and kept extensive species records and notes which were published in the RAOU journal (and *Handbook of the Birds of Western Australia).*

Within this first phase, it was soon apparent that the Kookaburra was well suited to its adopted environment and had become so widespread and numerous it was classified as 'common'; especially "in wooded areas" (Serventy, 1948, p. 286)**.** The data from the present study (Table 7.6) show that within a decade of arriving in the study area the species was present in suburbs to the south, at South Perth, south-east at Armadale, and north-east at Bassendean. It was also present as well at rural coastal localities as far south as Augusta on the Southwest Peninsula, and at Bluff Knoll, Albany. It was also an occasional visitor to Carnac Island (Serventy, 1938).

During the following decades, from 1909 - 1929, the species continued its spread into coastal and inland localities that supported eucalypt forest and cultivated lands used for dairy farming, fruit-growing and cropping, including Bunbury, Busselton, Denmark and Bridgetown. By the 1940s it had "invaded all suitable habitat" (Saunders & Ingram, 1995, p. 156). In the ensuing decades, 1930 – 1950 the species was recorded at coastal localities such as Dunsborough and Ludlow, as well as to the north, and north-east of Perth, inland, at Gingin, and Gidgegannup. It had also breeched the scarp and was recorded in the Darling Ranges at Glen Forest.

From this point, up to the close of Era A in 1955, the species continued to disperse widely. A number of coastal localities along the Southwest Peninsula, including Margaret River, Cape Naturaliste, Vasse, Witchcliffe and Yallingup and Yelverton recorded sightings. Inland, the habitat and conditions of the heavily timbered Jarrah and Karri forests were proving well suited to the ecological needs of the species. Sightings were recorded at Manjimup, Nannup, Pemberton, and Yornup. However, the species were not limited to wooded areas, and was recorded as far east as York and Nyabing, in the sparsely vegetated and lightly timbered Wheatbelt.

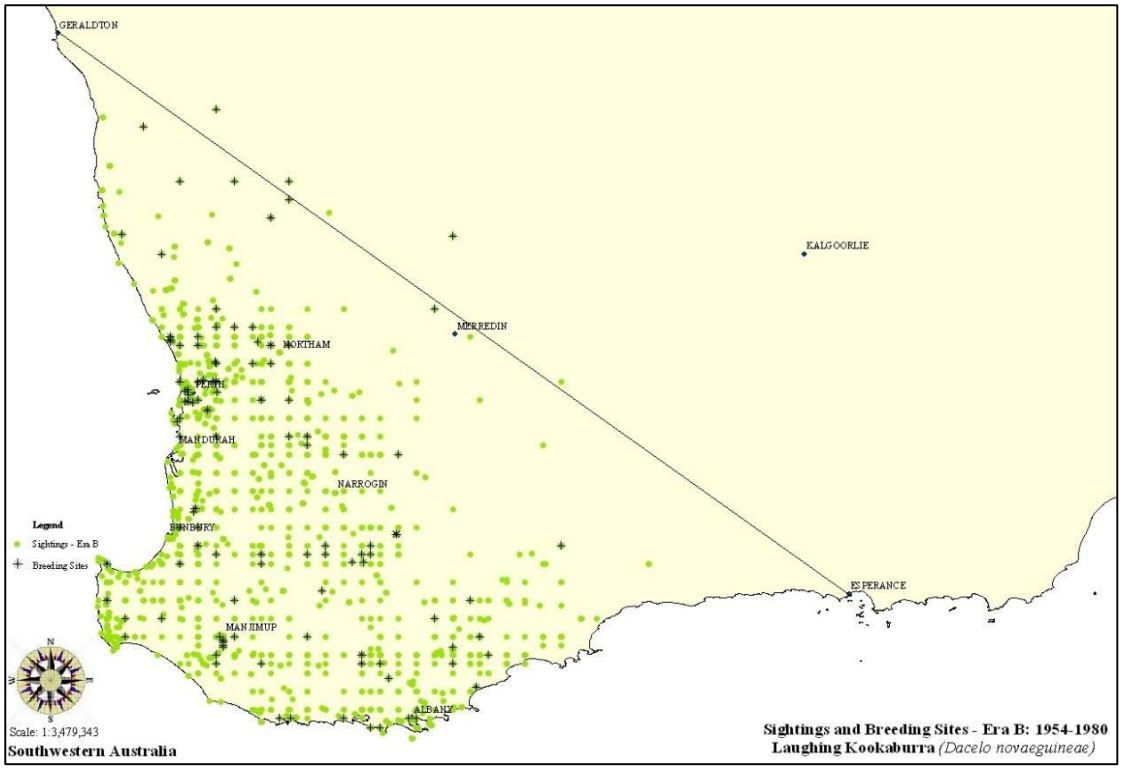
Between the mid-1930s and early 1950s urban populations spread out in all directions: east to Guildford, west to the Kings Park bushland and to Karrakatta, north to Mt Hawthorn and south to Jandakot. By the mid-1950s dispersal extended to the coast with sightings recorded at Swanbourne. The population was also extending beyond the urban-rural fringe into settlements to the east at Wooroloo and Northam, north at Yanchep, Mogumber and Moore River and the south, at Mandurah. They had also become used to the city-scape, with a pair seen in Perth with "their beaks turned skywards and their throats working full pressure" (Anon, 1952).

Table 7.6: Laughing Kookaburra, locality sightings, Era A: 1898 – 1953
(Source: The Present Study)

Laughing Kookaburra Era A Sightings: 1898 – 1953 – Urban and Rural					
Year	**Location**	**Year**	**Location**	**Year**	**Location**
1898	Armadale	1935	Gooralong Brook	1953	Nyabing
1898	South Perth	1936	Guildford	1953	Parkerville
1903	Augusta	1936	Harvey	1953	Pemberton
1904	Bassendean	1937	Iffley Brook	1953	Picton
1908	Bluff Knoll	1937	Jandakot	1953	Pinjar
1909	Bridgetown	1937	Karrakatta	1953	Pinjarra
1922	Bunbury	1938	Karridale	1953	Regans Ford
1923	Busselton	1938	Kings Park	1953	Rockingham
1926	Byford	1949	Lake Grace	1953	Stockyard Gully
1927	Carbunup River	1949	Ludlow	1953	Swanbourne
1927	Lake Cooloongup	1950	Mandogalup	1953	Vasse
1928	Coolup	1950	Mandurah	1953	Wanneroo
1929	Cowaramup	1950	Manjimup	1953	Waroona
1929	Crawley	1950	Margaret River	1953	Wellard
1929	Denmark	1950	Marybrook	1953	West Midland
1930	Donnelly River	1950	Melville	1953	West Midland
1930	Donnybrook	1950	Midland	1953	West Midland
1931	Dunsborough	1950	Mogumber	1953	White Lake
1932	East Cannington	1950	Moingup Spring	1953	Witchcliffe
1932	Eclipse Island	1950	Moore River	1953	Wonnerup
1933	Flinders Bay	1950	Mount Hawthorn	1953	Wooroloo
1933	Floreat	1951	Mundaring Weir	1953	Yallingup
1934	Forest Grove	1951	Nangeenan	1953	Yanchep
1934	Garden Island	1951	Nannup	1953	Yelverton
1935	Gidgegannup	1951	Native Dog Swamp	1953	York
1935	Gingin	1951	Naturaliste, Cape	1953	Yornup
1935	Glen Forrest	1951	Nedlands		
1935	Glen Mervyn	1951	Northam		

In 1948, the species is described as “firmly established in the South-west forested country, north to the Moore River and Cockleshell Gully” (Serventy & Whittell), as well as “a casual visitor east of Northam to Kellerberrin and south-east to Gnowangerup and Lake Grace” (1948, p. 230). Whilst the data from the present study support this, they also indicate that the species is firmly enough established throughout the study area that it was not to be stopped by either death, or captivity.

7.9.3 Era B: 1954 – 1980: Establish, or Fail:



Map 7.2: Dispersal of Laughing Kookaburra, Era B: 1954 – 1980
(Including Breeding)

By the commencement of Era B (•) 1954-1980, *Establish or Fail* phase (Map 7.2), the species had established widespread permanent populations. Rumblings had begun as to the wisdom of acclimatising the species to the Southwest as they had become so numerous and earned a reputation for being predatory on local wildlife, particularly birds. In 1954 a visiting dignitary publicly condemned the introduction of the species to the State after hearing it "had 'eaten out' a number of small, beautiful W.A. birds" (Hora, 1954).

The criticism is lent support from the Curator of the Perth Museum, who released a statement that the "tragedy of the kookaburra may, in the long run, provide to be as serious in this State as the introduction of the rabbit and the fox" (Glauert, 1954); adding that its arrival "has certainly brought about a diminution in the numbers of many of our small insectivorous birds". Another critic is concerned that there "must be millions of them here now" (Holloway, 1954, p. 24); and warns they are "increasing rapidly every year and the little birds are decreasing".

A similar litany heralded the close of the Era; with WA farmers proposing the species be "declared vermin on the grounds that it is destroying small native birds" (Douglas, 1980); although the request was opposed and deemed "quite absurd". To that point, and to that date, there is no conclusive evidence to support these suppositions.

By the 1960s, says Long (1988, p. 6) the species "was firmly established in the south west forested country" from Jurien Bay (200km north of Perth) to Albany (400km south-east of Perth). A colony had also established offshore at Bald Island (about 1.5km off the coast at Cheyne's Beach near Albany). To the north, the species was sighted at Arrino, south of Dongara in 1962 (Serventy & Whittell, 1962).

Long also subscribes to the view that at this time, the species had not established permanent populations "beyond Moora, Bolgart and the Great Southern Railway" (1988, p. 6). Rather, he says, sightings of the species at Kellerberrin, Nangeenan, Dangin, Lake Grace, Lake King, Holt Rock, Gnowangerup and Borden, were probably "temporary invasions". However, he concedes that at the time of writing, the species "is now a permanent or semi-permanent resident in many of these areas", albeit limited to areas where there is a permanent water supply.

Whilst this may have been the case throughout the 1960s, data from the present study, which covers the period 1954-1980, indicate there were more than occasional visitors to inland areas. In fact, the density and extent of spread of the species increases markedly between Era A, the first stage, and Era B, the second stage of the invasion. The inland populations are now extending well beyond the timbered and cultivated Southwest Peninsula, heavily into the Central and Southern Wheatbelt. Areas, which although they receive only limited rainfall, have a water supply sourced from farm and railway dams and homesteads.

The movement of the species into rural areas was extensive during Era B (Table 7.7). New locality listings include the now Ramsar listed Lake Muir, as well as sites along the Waychinicup and Fitzgerald Rivers (and associated National Parks). These areas are of important natural heritage, as they support migratory as well as rare and endangered birds.

The Kookaburra also established populations on a number of offshore islands adjacent to the south, south-east coast, including Chatham, Michaelmas, Breaksea and Bald Islands. These islands host migratory as well as resident birds. Bald Island is part of the Mount Manypeaks and Two People's Bay 'Important Bird Area' and is a World Conservation Union Category reserve. It is a breeding ground for Little Penguin (*Eudyptula minor*) and Great Winged Petrel (*Pterodroma macroptera*). It also supports a translocated population of the rare Noisy-Scrub Bird and a unique skink species, Red-legged Ctenotus (*Ctenotus labillardieri*) (Birdlife International, 2011b) which is restricted to the southernmost corner of the State.

Table 7.7: Laughing Kookaburra: Era B: 1954-1980 – Rural Sightings Summary
(Source: The Present Study)

Laughing Kookaburra: Era B Sightings: 1954 - 1980 - Rural									
Year	**Location**	**Year**	**Location**	**Year**	**Location**	**Year**	**Location**	**Year**	**Location**
1954	Bindoon	1958	Dawesville	1959	Napier	1963	Karribank	1975	Chatham Island
1954	Brookton	1958	Dinninup	1959	Needilup	1963	Mount Clarence	1975	Eaton
1954	Clackline	1958	Flybrook	1959	New Norcia	1963	Mount Manypeaks	1975	Michaelmas Island
1954	Cookernup	1958	Gingin Brook	1959	Perup River	1963	Mount Taylor	1975	Wokalup
1954	Dangin	1958	Granite Peak	1959	Waddington	1963	Pingelly	1975	Wongamine
1954	Katanning	1958	Jarrahdale	1959	Wandering	1963	Wagin	1975	Yornaning
1954	Kenwick	1958	Jingalup	1959	Waychinicup River	1963	Warriup	1975	Yunderup
1954	Narrogin	1958	Kalannie	1959	Wungong	1963	Wilson Inlet	1976	Chandala Spring
1954	Wagerup	1958	Kent River	1959	Yewadabby Spring	1964	Bunker Bay	1977	Boddington
1954	Williams	1958	Kojonup	1960	Arramall Lakes (Dongara)	1964	Jurien	1977	Lake Bambun
1955	Beverley	1958	Lake Clifton	1960	Arthur River	1964	Mount Lesueur	1977	Wellington Mill
1955	Dryandra	1958	Lake Muir	1960	Bailup	1964	Wungong Brook	1978	Caversham
1955	East Beverley	1958	Lake Preston	1960	Bindoon Hill	1965	Bakers Hill	1978	Dudinyillup
1955	Northcliffe	1958	Manypeaks	1960	Broomehill	1965	Muchea	1978	Jalbarragup
1955	Warren River	1958	Mayanup	1960	Cervantes	1965	The Lakes	1978	Jerramungup
1955	West Busselton	1958	Mount Barker	1960	Cuthbert	1966	Benger Swamp	1978	Magenup Swamp
1956	Carey Brook	1958	Myalup	1960	Devils Slide	1966	Broke Inlet	1978	Maidment Gardens
1956	Collie	1958	Nornalup Inlet	1960	Grasmere	1966	Mount Frankland	1978	Mount Saddleback
1956	Collie-burn	1958	Quindalup	1960	Mooliabeenee	1966	Walebing	1978	Sues Pool
1956	Dumbleyung	1958	Quindanning	1960	Mount William	1967	Congelin	1978	Warner Glen
1956	Scott River	1958	Quinninup	1960	North Dandalup	1967	Cooleenup Island	1979	Avon River
1956	Shannon	1958	Rocky Gully	1960	Preston Beach	1967	Highbury	1979	Calyerup Creek
1956	Wellington Dam	1958	Tallanalla	1960	Quarmup	1968	Cervantes (The Pinnacles)	1979	Cowalellup Waterhole
1956	Windy Harbour	1958	Twin Peaks	1960	Serpentine River	1968	Jitarning	1979	Logue Brook
1957	Castle Rock	1958	Vasse River	1960	Torbay	1968	Lancelin	1979	Ravensthorpe
1957	Frenchman Bay	1958	Walpole	1960	Wallcliffe Cave	1970	Fitzgerald River	1979	Toodyay
1957	Kellerberrin	1958	Wannamal	1961	Australind	1970	Martins Tank Lake (Yalgorup)	1979	Wedge Island
1957	Kwolyin	1958	Warren National Park	1961	Bannister	1970	North Bannister	1979	William Creek
1957	Lake Seppings	1958	Weld River	1961	Eastbrook	1970	Quairading	1979	Woodanilling
1957	Moora	1958	William Bay	1961	Nornalup	1971	Gingin South	1979	Yarloop
1957	Mundijong	1959	Badgingarra	1961	Torbay Inlet	1971	Greenshield Soak	1979	Yatheroo
1957	Namban	1959	Bald Island	1961	Two Peoples Bay	1971	Lake Magenta	1980	Alexandra Bridge
1958	Arumvale	1959	Chester Pass	1962	Boyup Brook	1971	Mission Lake	1980	Boranup
1958	Beermullah Lake	1959	Cockleshell Gully	1962	Chidlow	1972	Gnowangerup	1980	Cairlocup
1958	Borden	1959	Crossman	1962	Gardner River	1972	Sullivan Soak	1980	Capel
1958	Bowelling	1959	Greenbushes	1962	Kendenup	1973	Point Peron	1980	Elgin
1958	Boyanup	1959	Guilderton	1963	Albany	1974	Baramba	1980	Hamelin Bay
1958	Calingiri	1959	Hill River	1963	Boyagin	1974	Dongolocking	1980	King River
1958	Capercup Well	1959	Kalgan	1963	Fort Valley	1974	Fitzgerald River National Park	1980	Kudardup
1958	Carlotta	1959	Lake Hayward	1963	Harvey Dam	1974	Leschenault Estuary	1980	Lake Davies
1958	Dandaragan	1959	Mialla Lagoon	1963	Howe, West Cape	1975	Binningup	1980	Lake Josephine
1958	Darkan	1959	Nambung River	1963	Kalgan River	1975	Breaksea Island	1980	Leeuwin, Cape

Urban and coastal populations built up (Table 7.8) with sightings extending into a number of new suburbs including those of Herdsman Lake and Bibra Lake, situated near permanent wetland; as well as the riverside suburbs of Shoalwater and Woodman Split. The species also spread further throughout the Darling Range, into Kalamunda and Lesmurdie, as well as the foothills at Forrestfield.

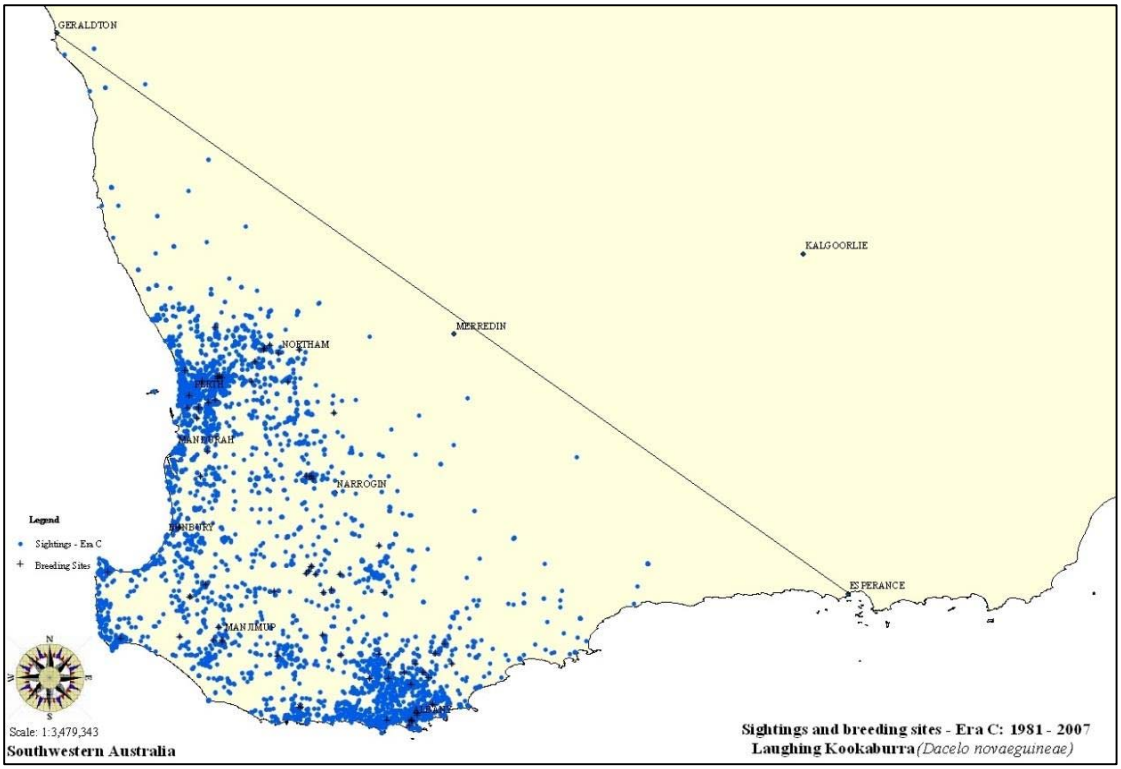
There was further movement beyond the urban-rural fringe past Yanchep, at Loch Ness and into the outer hills suburbs of Bedfordale, Karragullen, Mundaring and Red Hill. To the north they spread into the outlying suburbs of Neerabup and Joondalup; and north-east into Ellenbrook and Whiteman. To west, along the coast, there were sightings at Kwinana, City Beach and Sorrento.

Table 7.8: Laughing Kookaburra: Era B: 1954-1980 – Urban Sightings Summary
(Source: The Present Study)

Laughing Kookaburra Era B Sightings: 1954-1980 - Urban			
Year	**Location**	**Year**	**Location**
1954	Bull Creek	1967	Herdsman Lake
1954	Kwinana	1969	Wembley
1955	Bedfordale	1971	Ellen Brook
1955	City Beach	1971	Neerabup
1957	Bickley	1973	Middle Swan
1959	Karragullen	1975	Whiteman
1959	Red Hill	1976	Woodman Spit
1960	Sorrento	1977	Jandabup
1960	Upper Swan	1977	Lake Joondalup
1962	Kalamunda	1977	Lock McNess
1962	Mundaring	1978	Bayswater
1962	Shoalwater	1978	Lesmurdie
1964	Bibra Lake	1979	Claremont
1967	Forrestfield	1980	Kallaroo

By the close of Era B, it is evident that the species is not inhibited by changes in habitat, in terms of settling rural and urban environments. Nor is dispersal limited to habitats that are predominantly timbered or cultivated. Rather, the species is able to settle and breed in a range of habitat types. Its ecological flexibility is no doubt aided by its sedentary nature and intrinsic territoriality which enables it to maintain a permanent habitat patch that provides all ecological needs. These features, along with its ability to subsist on a varied diet, and physical attributes that make it adept at foraging and conserving energy, make it an able invader, and one not fated to fail.

7.9.4 Era C: 1981 – 2007: Spread, or Remain Local:



Map 7.3: Dispersal of Laughing Kookaburra, Era C: 1981 – 2007
(Including Breeding)

By Era C (•) 1981-2007, *Spread or Remain Local* phase (Map 7.3) the presence of Laughing Kookaburra had increased across rural areas within the study area (Table 7.9). The only exception of this was along the eastern margin where sightings had contracted to some extent since Era B. It is an area of low rainfall that has been cleared for dryland agriculture. An essential element in the Kookaburra requirements is access to a reliable water supply, which is probably lacking in this region.

Conversely, sightings on the Southwest Peninsula, south from Busselton to Augusta had increased. This area contains cultivated lands and extensive viticulture but still retains substantial area of uninterrupted bush in conservation reserves.

However, the concentration of sightings around Walpole, Denmark, Albany and Mt Barker is greatest. The settlements of Walpole and Denmark are situated within the 'Warren' botanical district; a heavily forested area renowned for its botanical and faunal biodiversity. Whilst the forests present an impenetrable barrier to other introduced species (and some native species), they have proven a haven for the Laughing Kookaburra. The settlements of Mt Barker and Albany represent urban settlements but the areas are still wooded to some extent, having been cleared for farming; but not so much as to deter the Kookaburra.

Table 7.9: Laughing Kookaburra: Era C: 1981-2007 – Rural Sightings Summary
(Source: The Present Study)

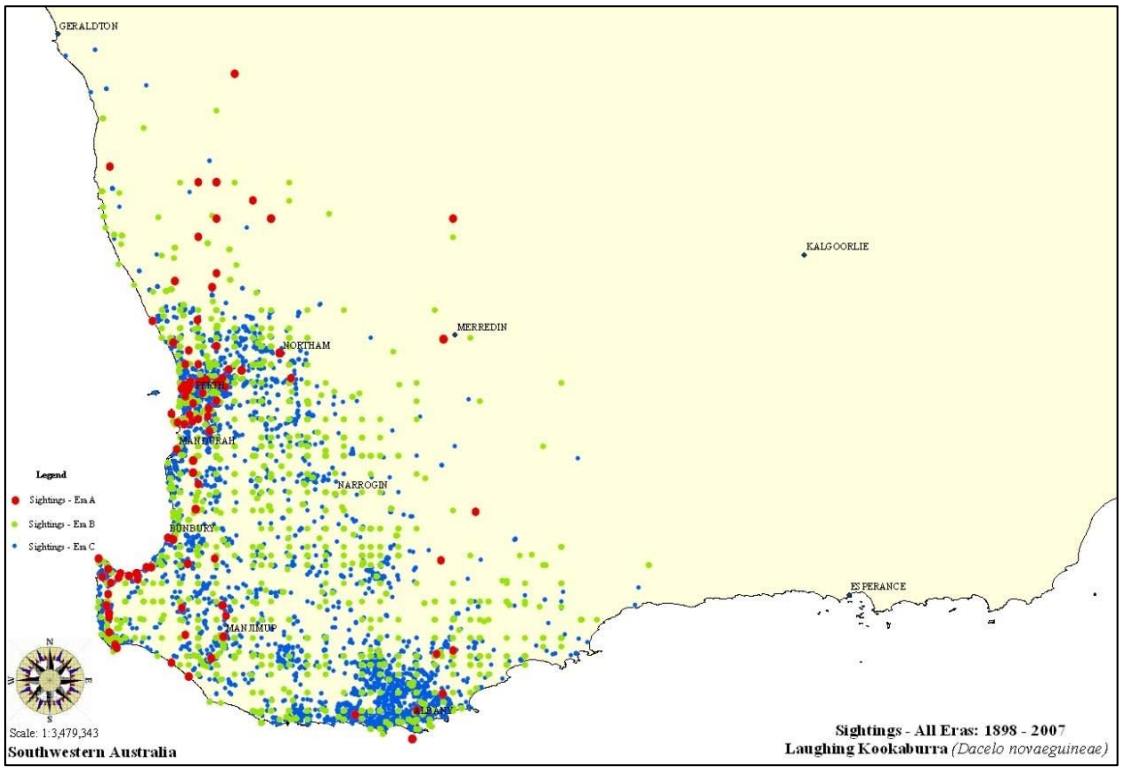
Laughing Kookaburra: Era C Sightings: 1981 - 2007 - Rural							
Year	**Location**	**Year**	**Location**	**Year**	**Location**	**Year**	**Location**
1981	Beaufort Inlet	1985	Gordon Inlet	1991	Karakin Lakes	1997	Denbarker
1981	Cataby	1985	Hamersley River	1991	Perup	1997	Lake Eyrie
1981	Jewel Cave (Margaret River)	1985	Keysbrook	1991	Victoria Plains	1997	Frankland
1981	Leeuwin-naturaliste N.P.	1985	Kybulup Pool	1991	William Bay N.P.	1997	Irwin
1981	Leschenaultia, Lake	1985	Millers Basin	1992	Boonanarring Brook	1997	Mount Frankland N.P.
1981	Lake Leschenaultia	1985	Quaalup	1992	Lake Kogolup	1997	Nanarup
1981	Peaceful Bay	1985	Tordit-gurrup Lagoon	1992	Stinton Cascades N.R. (Karragullen)	1998	Cardup
1981	Quarry Bay (Leeuwin)	1985	Watheroo N.P.	1992	Tutanning N.R.	1998	Cuballing
1981	Wellesley River	1986	Amelup	1993	Lake Mealup	1998	Dongara
1982	Bullsbrook	1986	Boyagin N.R.	1993	Narrogin	1998	Greenough
1982	Dwellingup	1986	Julimar Spring	1993	Serpentine	1998	Karnup
1982	Emu Point	1986	Lane Poole Reserve	1994	Bashford Nature Reserve (Nilgen)	1998	Tambellup
1982	Lake Hurlstone	1986	Lewana	1994	Cranbrook	1999	Beermullah(Big Bootine Swamp)
1982	Walpole-nornalup N.P.	1986	Mount Kokeby	1994	Hardy Inlet	1999	Coorow
1982	Lake Wannamal	1986	Serpentine N.P.	1994	Kamballup	1999	Yoganup
1983	Chittering	1986	Stirling Range N.P.	1994	Kooljerrenup N.R.	2000	Boorara Brook
1983	Emu Falls	1987	D'entrecasteaux N.P.	1994	Marrinup	2001	Kendenup
1983	Kondinin	1987	Porongurup N.P.	1994	Miling	2003	Beenyup Pool
1983	Yalgorup N.P.	1987	Shannon N.P.	1994	Mingenew	2003	Cheyne Beach
1984	Baldivis	1987	Wellington Mill	1994	Nambung N.P.	2003	Glenbrook (Margaret River)
1984	Chandala N.R.	1988	Lesueur N.P.	1994	Peel Inlet	2004	Noble Falls
1984	Mealup Point N.R.	1988	Pelican Point	1995	Bremer Bay	2004	Talbot Brook
1984	Mooradung N.R.	1988	Powlalup N.R.	1995	Marradong	2005	Christmas Tree Creek
1984	Nanga	1988	Torndirrup N.P.	1995	Udumung N.R.	2005	Gleneagle (Jarrahdale)
1984	Ongerup	1988	Tuart Forest N.P. (Busselton)	1996	Burekup	2006	Blackboy Gully (Wandering)
1984	Pingrup	1989	Quindalup	1996	Dardanup	2006	Ellendale Pool
1984	Wungong Dam	1990	Lake McLarty	1996	Duranillin	2006	Narembeen
1985	Bornholm	1990	Wambyn N.R.	1996	Nallian N.R. (Wagin)	2006	Lake Wilson (Nannup)
1985	Byenup Lagoon (Lake Muir)	1990	Wickepin	1996	North Pinjarra	2007	Dowerin
1985	Crystal Springs	1991	Doopiter Swamp	1997	Balingup	2007	Lake Bryde N.R.

In urban areas (Table 7.10) sightings from Perth, south to Mandurah had become heavily concentrated. Similarly, the sightings along the northern corridor to Yanchep, and through the eastern hills to Northam became more concentrated. Overall, the species had spread between previously settled suburbs, taking up available space and resources. By this Era, it had been recorded at the Ramsar listed wetland, Thomsons Lake, an area covered under the international migratory bird agreements (Japan-Australia, JAMBA; and China-Australia, CAMBA) treaties.

Table 7.10: Laughing Kookaburra: Era C: 1981-2007 – Urban Sightings Summary
(Source: The Present Study)

Laughing Kookaburra: Era C Sightings: 1981 - 2007 - Urban					
Year	**Location**	**Year**	**Location**	**Year**	**Location**
1982	Alfred Cove	1988	Cannington	1997	Yellagonga Regional Park (Joondalup)
1982	Applecross	1988	North Lake	1998	Ellis Brook (Martin)
1982	Maylands	1989	Carine (Big Carine Swamp)	1998	Middle Swan
1983	Beeliar (Brownman Swamp)	1990	Lake Goollelal	1998	Shelley
1983	Hovea (John Forrest N.P.)	1990	Lake Gwelup	1999	Woodbridge (Marshall Park)
1983	Shenton Park	1990	Star Swamp (North Beach)	1999	South Lake
1983	Wattleup	1991	The Spectacles (Kwinana)	2000	Perth Airport (Redcliffe)
1984	Eglinton	1992	Lake Kogolup (Kwinana)	2000	Victoria Dam (Munday Brook)
1984	Forrestdale Lake	1992	Pinnaroo Park (Whitfords)	2001	Redcliffe (Garvey Park)
1985	Lake Amarillo (Keralup)	1993	Brentwood (Blue Gum Reserve)	2001	Banjup (Gil Chalwell Reserve)
1985	Bickley Brook	1993	(Ascot) Grove Farm Reserve	2001	Cannington (Kent Street Weir)
1985	Challis	1994	Balga (Brian Burke Reserve)	2001	Langford
1985	Mount Gorrie (Helena Valley)	1994	Lake Claremont	2002	Riverton
1985	Kelmscott	1994	Lake Coogee	2002	Ardross (Wireless Hill Park)
1985	Stony Brook (Roleystone)	1994	Jolimont	2003	Helena River
1986	Thomsons Lake N.R. (Beeliar)	1994	Manning Lake	2003	Lake Richmond (Rockingham)
1986	Point Walter	1994	Lake Monger	2004	Blackwall Reach
1986	Point Walter	1994	Swan View	2004	Burswood
1987	Helena Valley	1994	Woodvale N.R.	2005	Craigie
1987	Walyunga N.P. (Bullsbrook)	1997	Trigg Bushland	2005	Kardinya
1987	Yanchep N.P.	1997	Warwick	2007	Heirisson Island
1987	Lake Yangebup				

7.9.5 Chronology of Dispersal: All Eras: 1898 – 2007:



Map 7.4: Chronological Dispersal of Laughing Kookaburra, All Eras: 1898 – 2007

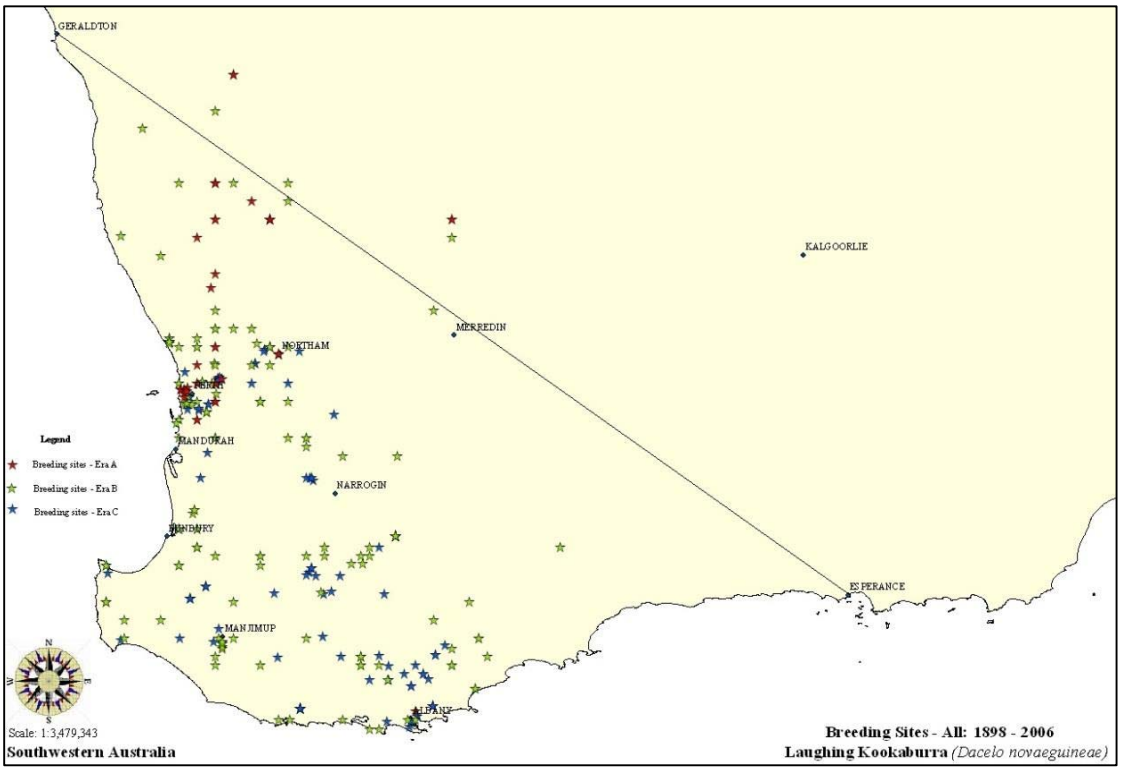
The presentation of all data chronologically is represented by: Era A (•) 1898-1953; Era B (•) 1954-1980; and Era C (•) 1981-2007 (Map 7.4). From the depiction of the data from 1898-2007, it is easy to see the pattern of outward spread eastward from the release sites and early colonised sites of Era A, 1898-1953. The records are focussed in the metropolitan area; close to the Zoological Gardens, South Perth, which was the site of numerous consecutive liberations.

Other than the urban releases, there were also liberations south of Perth at Serpentine, Pinjarra and along the Blackwood River. To the north there were liberations at Gingin, Mullewa, Irwin and Mingenew. Other independent liberations were probably responsible for the sightings recorded south-east of Narrogin and near Albany and Mt Barker.

By Era B, 1954-1980, the species had dispersed widely from the release sites across the Southwest Peninsula. They had spread eastward through heavily forested areas into areas of dryland agriculture. However, the records become sparser as they progress east, away from preferred habitats and into an area of low rainfall.

The representation of Era C, 1981-2007, data shows the extent of the contraction along the eastern boundary, and within the north-eastern sector (which displays only Era A and Era B records). It also shows the intensification of populations on the Swan Coastal Plain and between Walpole, Denmark, Albany and Mt Barker.

7.9.6 Breeding: All Eras: 1898 – 2007:



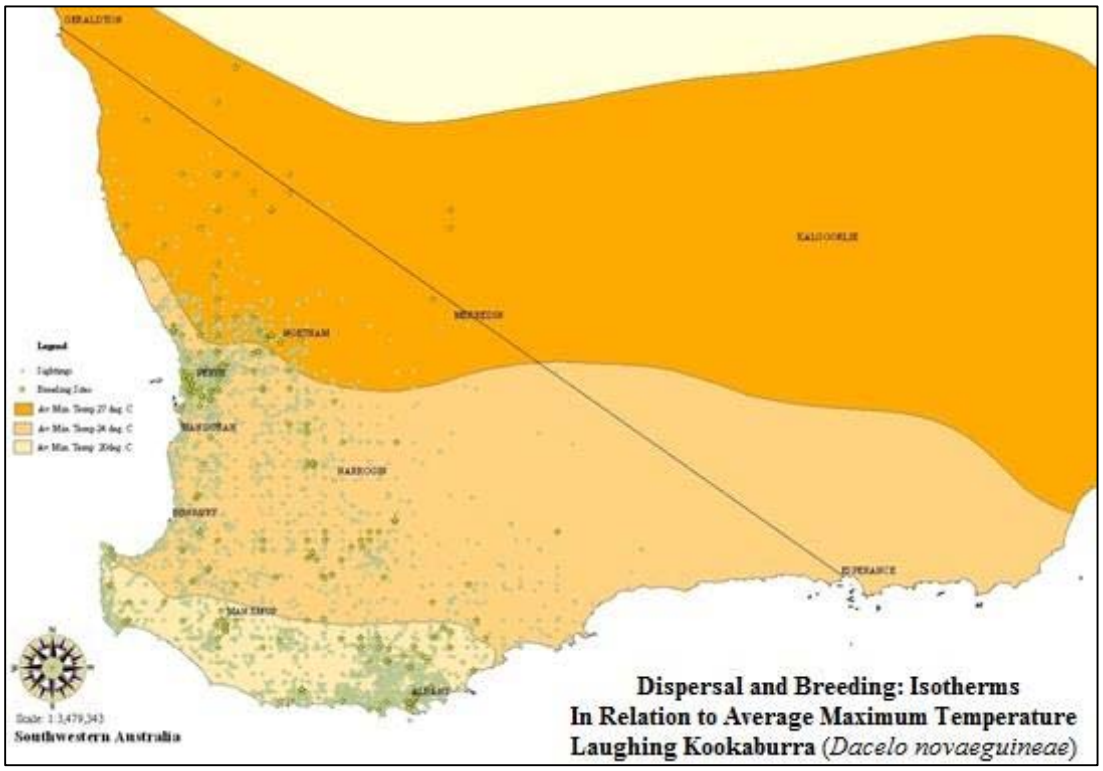
Map 7.5: Breeding: Laughing Kookaburra: All Eras 1898 – 2007

The breeding data is represented by: Era A (□) 1898-1953; Era B (□) 1954-1980; and Era C (□) 1981-2007 (Map 7.5). In terms of breeding: it is evident that within Era A, the species had acclimatised quickly and commenced propagation within a year of being released. A report in December 1899 recalls that the bird had "bred this year at least in one locality" (ACWA, 1899, p. 60). With a few years, by the early 1900s, it was described as "thriving and breeding well, especially about the cultivated districts" (Le Souëf, 1902). A report from Donnybrook details that a pair "have nested and have two young ones flying about with them"; and nearby "a small colony of liberated Jackasses have established themselves, and are now surrounded by their small ones" (Stray Feathers, 1903, p. 159).

By 1926 it was reported as breeding along the Avon River (Saunders & Ingram, 1995); and by the 1930s in Bunbury; with a local resident reporting that the birds, which have their "own exclusive haunt" had nested in "a veteran tuart gum which must have witnessed the foundation of Bunbury" and have for the past four years… successfully brought up a brood of young (Whitlock, 1939, p. 53).

Overall, the data show that breeding occurred in the north-east sector in Eras A and B, but not in Era C. Rather, breeding by the species in this latter era was limited to the Swan Coastal Plain and the southernmost regions, with breeding concentrated near Albany and Mount Barker where the species remains prolific.

7.9.7 Dispersal in Relation to Average Maximum Temperature:

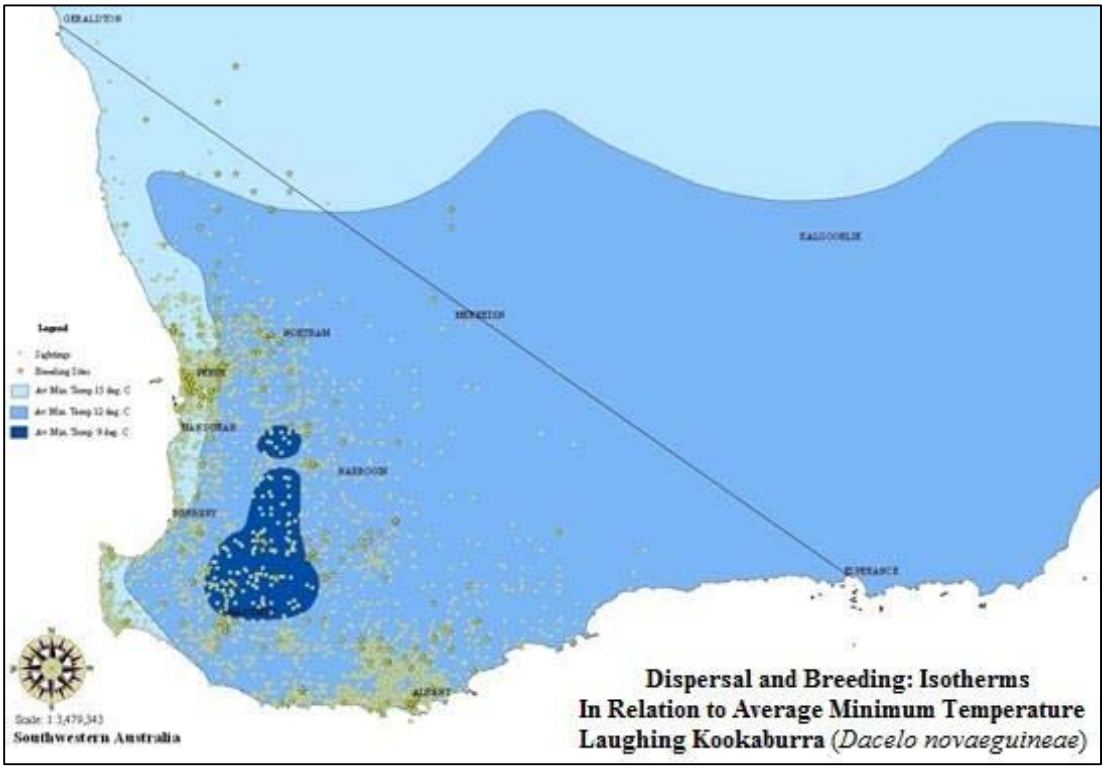


Map 7.6: Dispersal of Laughing Kookaburra In Relation to Average Maximum Temperature
(All Eras: 1898 – 2007) (Including Breeding)

The data is represented as: Sightings 1898-2007 (•); Breeding 1898-2007 (☆); and Temperature zones 27°C (□); 24°C (□); and 20°C (□) (Map 7.6). The dispersal of the Laughing Kookaburra is extensive and extends across all temperature zones, although, there are fewer sightings recorded in the 27°C zone than the 24°C and 20°C zones. The concentration of sightings around the metropolitan area between Perth and Mandurah, in the 24°C zone, is probably attributable to other factors than temperature. The metropolitan area has nature reserves, parks and gardens that provide roosting and nesting habitat as well as food, features that become scarcer as the species progresses eastward.

The other concentration of sightings, on the Southwest Peninsula between Busselton and Augusta, and also between Walpole, Denmark, Albany and Mt Barker fall within the 20°C zone, but again, this is probably attributable to habitat type than temperature. The environment around these settlements is heavily timbered and supports high levels of faunal biodiversity, an optimal environment for this woodland species. The pockets of concentrated sightings in this zone are in proximity to areas of human settlement. The urbanscape has proven ideal for the Kookaburra, as people enjoy interacting with nature and entice the bird into their garden by feeding meat and scraps. Amenities such as parks and reserves also provide roosting and nesting habitat.

7.9.8 Dispersal in Relation to Average Minimum Temperature:

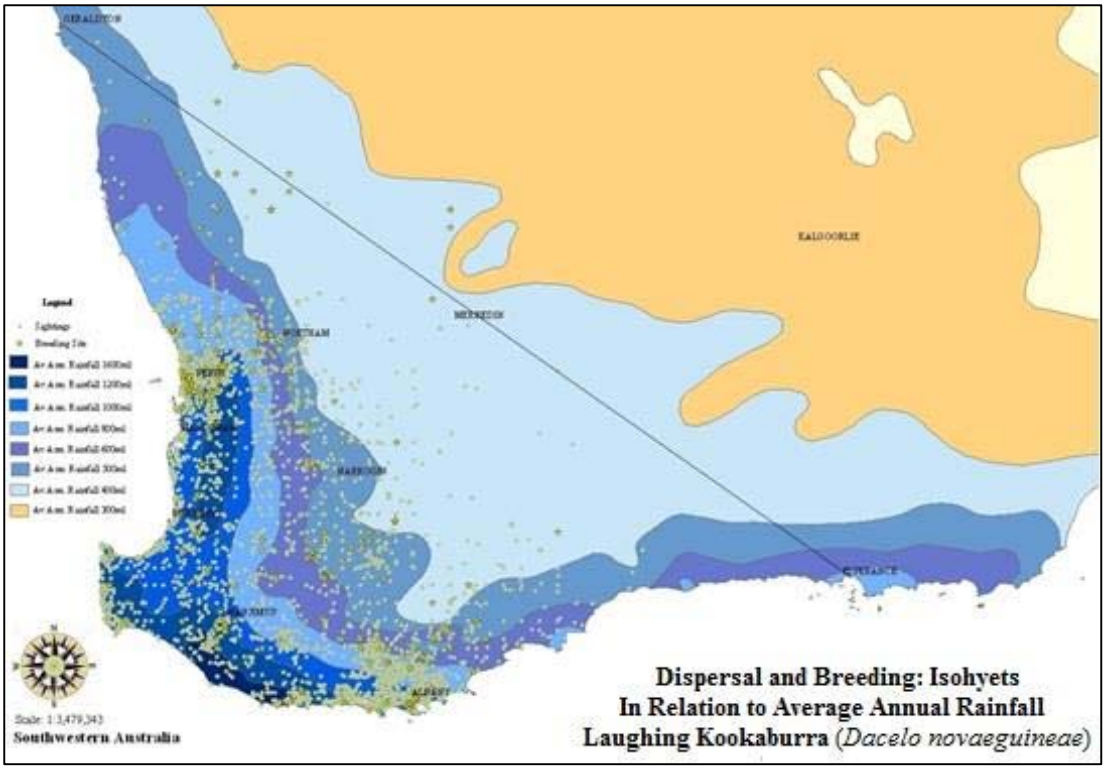


Map 7.7: Dispersal of Laughing Kookaburra In Relation to Average Minimum Temperature
All Eras: 1898 – 2007: (Including Breeding)

The data is represented as: Sightings 1898-2007 (•); Breeding 1898-2007 (☆); Temperature zones 15°C ( ); 12°C ( ); and 09°C ( ) (Map 7.7). The distribution of the Laughing Kookaburra in relation to Annual Minimum Temperature extends across all zones. The concentration of sightings in the metropolitan area fall within the 15°C zone; and those north and south of the metro area either in, or along the edge of the 12°C zone. However, it is unlikely that the concentration of sightings in this zone is influenced significantly by temperature; as widespread dispersal across all zones refutes this. As detailed previously, the concentration of sightings within the greater metropolitan area is probably linked to habitat conditions and food availability.

Similarly, the concentration of sightings along the Southwest Peninsula and south-east of there between Walpole, Denmark, Albany and Mount Barker, are probably linked to habitat preference rather than climate. The cooler conditions along the south-east coast have not prohibited the species from colonising there. Neither have the lower temperatures (in the vicinity between Boddington and Manjimup), deterred the species. For although it is the coldest region within the study area, it also has areas of forest and farm lands that are able to provision the species adequately.

7.9.9 Dispersal in Relation to Average Annual Rainfall:



Map 7.8:Dispersal of Laughing Kookaburra In Relation to Average Annual Rainfall (Isohyets)
All Eras: 1898 – 2007: **(**Including Breeding**)**

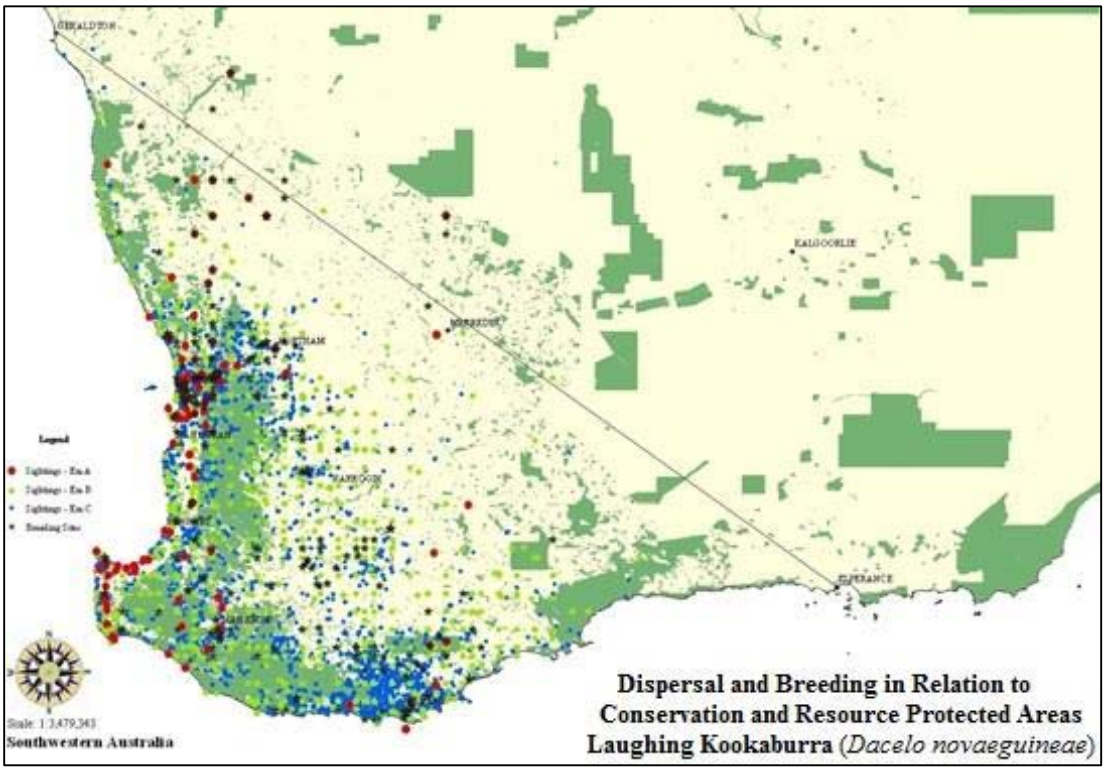
The data is represented as: Sightings 1898-2007 (•); Breeding 1898-2007 (☆); and Rainfall zones: 1600mm (□); 1200mm (□); 1000mm (□); 800mm (□); 600mm (□); and 500mm (□) 400mm ( ). The arid zone (□) (≤ 300mm) falls outside of the study area limits (Map 7.8). In relation to Annual Average Rainfall, the distribution of the Laughing Kookaburra extends across all zones.

However, sightings along the eastern border, within the 500mm zone, are much more sporadic. This zone is synonymous with cultivation of dryland agricultural crops. The landscape is extensively cleared, retaining few tall trees, and lacking permanent fresh-water sources, an essential territorial element for the success of the Laughing Kookaburra.

As with the temperature, the concentration of sightings around the metropolitan area, the Southwest Peninsula, and the south-east coastal districts is probably not so much influenced by the extent of rainfall, but by the presence of the habitat types characteristic of these districts that provide all necessary ecological requirements.

The widespread dispersal of the species across all rainfall zones evidences that it is not the extent of rainfall that is the main mitigating factor in site selection. However in combination with moderate temperatures and vegetation types, there are areas of preferential habitat which influences where the species settles.

7.9.10 Dispersal in Relation to Conservation and Resource Protected Areas:



Map 7.9: Dispersal of Laughing Kookaburra in relation to Conservation and Protected Areas
All Eras: 1898 – 2007: (Including Breeding)

The data for the Laughing Kookaburra in relation to 'Conservation and Resource Protected Areas' is represented by: Era A (•) Era B (•) Era C (•) and Breeding (□) (Map 7.9). Before proceeding to discussion of the spread of the Laughing Kookaburra within these areas, a brief explanation of the lands vested within them is in order. The descriptions provided are based on those outlined by Department of Environment and Conservation (DEC) (2008).

The designation of lands for these purposes is made under *the Land Administration Act* 1997 (Roselaar) whereby Crown lands are set aside for various purposes. Once designated, the area is assigned to an appropriate body for management (such as a local government authority). The creation of national parks, conservation parks and nature reserves is the responsibility of the LAA. The creation of State forest and timber reserves, come under the jurisdiction of the *Conservation and Land Management Act 1984* (CALM Act) and are administered by DEC (formerly called Department of Conservation and Land Management).

Under the CALM Act, national parks, conservation parks, nature reserves, State forest and timber reserves are automatically vested in the Conservation Commission of Western Australia. The vested lands are classified as Class A reserves, to reflect their level of tenure, i.e. the approvals required to alter the reserve's area, purpose or classification.

National parks possess attributes of national significance for their scenic, cultural or biological values. Recreation that maintains these values is permitted. Conservation parks possess attributes of local or regional significance. Both are managed to conserve the landscape and wildlife of the area, for use in scientific study and to preserve features of historical, scientific or archaeological interest. Recreational pursuits are not permitted that would adversely affect the ecosystems or landscapes contained in these areas.

State forests contain areas of indigenous vegetation and are managed for the purpose of nature conservation and recreation, to protect water catchments, and for sustainable timber harvests. Timber harvests are regulated under the *Forest Products Act* 2000 and other enterprises such as apiary and harvesting of flora are also permitted.

Lands vested under sections 5(1)(g) or 5(1)(h) of the CALM Act are managed by the Conservation Commission for multi-purpose use including recreation and conservation. Sections in the former were created under *the Land Act 1933* and the latter by the LAA.

Regional parks are areas of open space that possess regionally significant values for landscape, conservation, and recreation. There are eleven regional parks in the Greater Perth Metropolitan area. They protect foreshore areas, beaches, wetlands and the Darling Scarp.

There are five dominant tree species throughout the Southwest conservation reserves and national parks: Marri (*Eucalyptus calophylla*), Jarrah (*E. marginata*), Karri (*E. diversicolor*), Tingle (*E. jacksonii*) and Tuart (*E. gomphocephala*). The bushland to which they belong are ancient and house relic Gondwanan floristic and faunal species, many confined to these localities (Wardell-Johnson *et al.*, 2007).

The Jarrah forest extends approximately from Perth to Manjimup. It has been subjected to extensive logging and broadscale clearing for farming and agriculture. The localities of Dwellingup and Nannup provide good examples of this type of forest.

The Karri forest lies between Manjimup and Denmark. Within, Peppermint (*Agonis flexuosa*) and Karri Sheoak (*Allocasuarina decussata*) are interspersed, along with an array of native shrubs. The Gloucester and Warren National Parks contain this type of forest.

The Tingle forests of the Walpole-Nornalup National Park lay further south. They consist mainly of Red Tingle (*E. Jacksonii*), Yellow Tingle (*E. guilfoylei*) and Rate's Tingle (*E. brevistylis*). Red Tingle, are a long lived species, exceeding 400 years. They have the largest base of all the Eucalypts which sometimes reach a circumference up to 26m.

The Tuart Forest is only found along the Swan Coastal Plain from Jurien Bay to Busselton. The dominant species of the forest is the Tuart tree (*E. gomphocephala*). Tuarts are also long lived, with some surviving more than 500 years. The Southwest Tuart forest, is the largest area of pure Tuart remaining, and is protected by the Tuart Forest National Park, also referred to as Ludlow State Forest, situated between Capel and Busselton.

The way the Laughing Kookaburra has spread throughout 'Conservation and Resource Protected Areas' presents a very different scenario to that of the *Streptopelia* doves. Whereas the doves failed to penetrate to the barrier of the timbered forests with the dense understorey below, the Kookaburra has made the southern forests, which takes in the 'South Coast', 'South West' and 'Warren' faunal districts, its home.

Whilst the heaviest concentrations of sightings are within urban areas around the greater metropolitan area, the Southwest Peninsula, between Busselton and Augusta, and the south-east coastal districts, there is clearly a proliferation of sightings in conservation areas. As there were liberations in Era A, 1898-1953 (•), along the Blackwood River which passes through these forested areas (and spills at Augusta where sightings were concentrated), it is plausible that the Era B, 1953-1980 (•) and Era C, 1981-2007 (•) sightings relate to these initial introductions.

From this map, the gradual push eastward into the interior can be seen, with Era C sightings occurring inland as well as along the coast. It is interesting to note the concentration of breeding records between Narrogin and Manjimup that fall outside of conservation areas, within lands cleared for agriculture and sheep farming. The removal of the dense understorey may allow for easier access to prey.

The widespread presence of the Kookaburra in these conservation areas indicates it is well suited to the habitat. However the forests also support a number of species, some endemic, with populations classified as either 'Critically Endangered', 'Endangered', or 'Vulnerable' (Table 7.11). Some are a possible food choice for the Kookaburra, others share similarities in their feeding or breeding ecology.

Increased competition for available ecological resources can result in several outcomes such as niche overlap, or a narrowing of the niche, or even a species shift from its 'fundamental niche', to a 'realised niche' to survive. Each of the species that occupies the affected niches is impacted by resource limitation, which translates to decreased populations. For put simply, "there must be fewer individuals of each species, if there are more species altogether" (Perrins & Birkhead, 1983, p. 141-142). Whilst such a scenario may not be threatening to the future populations of the Kookaburra, which has consistently sustained a strong presence throughout these conservation areas since its introduction; it could be a critical factor for 'at risk' species, specifically those that are endemic to the Southwest.

An example of niche overlap can be related to similarities in the diet of the Kookaburra to the Noisy Scrub-bird. At the time of settlement by Europeans the latter species was present in Drakes Brook, Margaret River, Augusta, Torbay and Mount Barker-Albany. However habitat loss as a result of the frequent use of fire by forest managers and early settlers caused the decimation of its invertebrate food supply, which, along with "climatic oscillation, including long dry periods" caused its populations to decline. It was not reported at all from 1889-1961, until a remnant population was rediscovered in 1961 at Two People's Bay near Albany (Blakers *et al.*, 1984).

Subsequent to rediscovery, two sub-populations have been identified. The first occupies lands in coastal areas from Two Peoples Bay to Cheyne Beach, at sites that include Moates Lake-Gardner Lake, Mount Gardner, Angove River-Normans Inlet, Mount Manypeaks, Waychinicup and Mermaid Point, The other is located offshore, on Bald Island (Danks, Burbidge, & Smith, 1996; Gilfillan, Comer, Burbidge, Blyth, & Danks, 2007).

Table 7.11: Species 'At Risk' in Conservation and Protected Areas in the Study Area
(Adapted from Threatened Species List, 2013)

'Critically Endangered', 'Endangered' and 'Vulnerable' Faunal Populations of the Southwest, South Coast and Warren Districts of Western Australia			
Common Name	**Scientific Name**	**Status**	**Threat Type**
Millipede	*Atelomastix anancita*	Vulnerable	Potential Food Source
Millipede	*A. brennani*	Vulnerable	Potential Food Source
Millipede	*A. culleni*	Vulnerable	Potential Food Source
Millipede, Toolbrunup Atelomastix	*A. danksi*	Vulnerable	Potential Food Source
Recherche Atelomastix	*A. dendritica*	Vulnerable	Potential Food Source
Millipede	*A. flavognatha*	Vulnerable	Potential Food Source
Millipede	*A. grandis*	Vulnerable	Potential Food Source
Millipede	*A. julianneae*	Vulnerable	Potential Food Source
Millipede	*A. lengae*	Vulnerable	Potential Food Source
Millipede	*A. longbottomi*	Vulnerable	Potential Food Source
Millipede	*A. melindae*	Vulnerable	Potential Food Source
Millipede, Wedge Hill Atelomastix	*A. poustiei*	Vulnerable	Potential Food Source
Millipede	*A. priona*	Vulnerable	Potential Food Source
Millipede	*A. sarahae*	Vulnerable	Potential Food Source
Striped Atelomastix	*A. tigrina*	Vulnerable	Potential Food Source
Bluff Knoll Atelomastix	*A. tumula*	Vulnerable	Potential Food Source
WA Pill Millipede	*Cynotelopus notablis*	Endangered	Potential Food Source
Sarah's Pill Millipede	*Epicyliosoma sarahae*	Vulnerable	Potential Food Source
Recherche Dugite	*Pseudonaja affinis tanneri*	Vulnerable	Potential Food Source
White-bellied Frog	*Geocrinia alba*	Critical	Potential Food Source
Orange-bellied Frog	*G. vitellina*	Vulnerable	Potential Food Source
Sunset Frog	*Spicospina flammocaerulea*	Vulnerable	Potential Food Source
Tingle Trapdoor Spider	*Moggridgea tingle*	Endangered	Potential Food Source
Cape Leeuwin Freshwater Snail	*Austroassiminea letha*	Vulnerable	Potential Food Source
Margaret River Marron	*Cherax tenuimanus*	Critical	Potential Food Source
Margaret River Burrowing Crayfish	*Engaewa pseudoreducta*	Critical	Potential Food Source
Dunsborough Burrowing Crayfish	*E. reducta*	Endangered	Potential Food Source
Walpole Burrowing Crayfish	*Engaewa walpolea*	Vulnerable	Potential Food Source
Pygmy Perch	*Nannatherina balstoni*	Vulnerable	Potential Food Source
Carnaby's Cockatoo	*Calyptorhynchus latirostris*	Endangered	Nest Site Competition
Baudin's Cockatoo	*C. baudinii*	Endangered	Nest Site Competition
Forest Red-tailed Black Cockatoo	*C. banksii naso*	Vulnerable	Nest Site Competition
Noisy Scrub-Bird	*Atrichornis clamosus*	Endangered	Food Type Competition
Red-tailed Phascogale	*Phascogale calura*	Endangered	Food Type Competition
Brush-tailed Phascogale	*P. tapoatafa*	Vulnerable	Food Type Competition
Chuditch	*Dasyurus geoffroii*	Vulnerable	Food Type Competition

Attempts at captive breeding to boost re-stocking ultimately failed (Davies, Smith, & Robinson, 1982), making the preservation of wild populations vital to the species continuance.

Like the Kookaburra, which is described as mainly seeking prey that live near to, or on the ground (as per Legge, 2004), this species also feeds mainly on, or near the ground. Its preferred habitats are swampy areas close to eucalypt forests where it takes "large insects, including crickets and cockroaches, soft-bodied invertebrates and slaters" (Blakers *et al.*, 1984, p. 341). Other studies (Danks & Calver, 1993; Smith & Calver, 1984) also identified invertebrates, such as ants, beetles and spiders as major prey items of adult Scrub-birds.

Scrub-bird nestlings are also fed extensively on invertebrates, such as spiders, grasshoppers, crickets, cockroaches, earthworms, centipedes, millipedes, various insect larvae and, occasionally, small frogs and lizards, although spiders and grasshoppers constitute more than half of food items (Danks & Calver, 1993; Smith & Calver, 1984).

What is noteworthy here, is that within the first Era of its release in 1897-98, Kookaburra had become prolific in the Drakes Brook, Hamel and Warren districts, the latter which takes in the towns of Margaret River, Augusta, Torbay and Albany (Beard & Sprenger, 1984); all localities that Noisy Scrub-bird had been present in prior to the arrival of both Europeans and the Kookaburra. It also takes in Mount Barker, and the greater Albany area which encompasses Two Peoples Bay, Cheyne Beach, Moates Lake-Gardner Lake, Mount Gardner, Angove River-Normans Inlet, Mount Manypeaks, Waychinicup and Mermaid Point; all sites of the re-discovered populations of the Noisy Scrub-bird.

The overlap between the prey types taken by both species must apply greater competition pressure for these resources. Of the two, Kookaburra possesses a more robust physiognomy and physiology. It is also known to supplement its invertebrate diet with other small prey items such as reptiles, frogs, small mammals and birds, offering further ecological advantage.

The Kookaburra also shares a similar diet to the Red-tailed Phascogale (*Phascogale calura*), another endangered endemic species. This small mammal has also suffered severe population declines arising from habitat loss and sustains only limited populations in fragmented landscapes within parts of the Wheatbelt (west to Beverley and south to Katanning), and in Fitzgerald River National Park (Kitchener, 1981). It is also a ground feeding species that preys mainly on insects and spiders (Bradley, 1997), and occasionally small birds and mammals. All prey types which are taken by the Laughing Kookaburra.

Other than being abundant throughout the conservation reserves which retain the remnant forest habitats essential to the ongoing survival of these species, the Kookaburra has established a permanent presence in the Wheatbelt, the historic breeding range for endangered Carnaby's Black Cockatoo (*Calyptorhynchus latirostris*). This endemic species was once common throughout the eucalypt woodlands of the Wheatbelt but its population levels are now critical due to the broadscale destruction of its nesting habitat for agriculture.

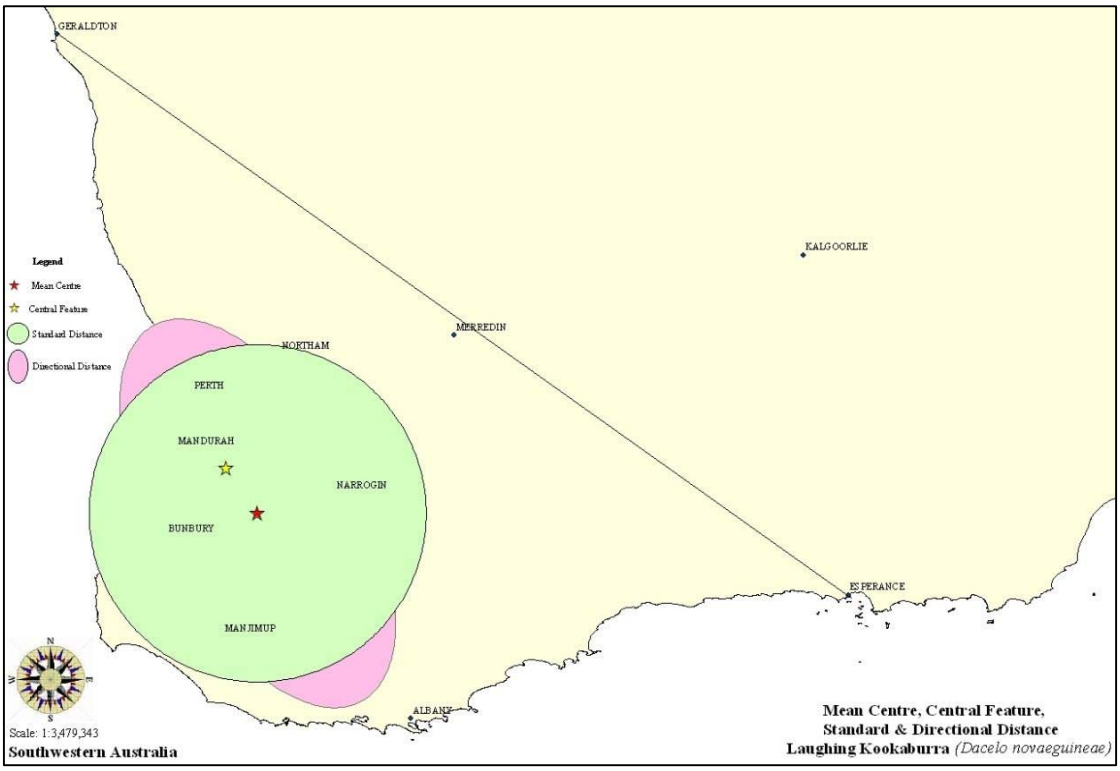
Remnant populations now breed in the Jarrah-Marri forests of the south-west sector of the study area, as well as along the Darling Scarp, and in the vicinity of Lake Clifton and Bunbury (Cale, 2003; Johnstone, Johnstone, & Kirby, 2008; Johnstone, Johnstone, Kirby, & Humphreys, 2006; Storr, 1991). Like another western endemic, Baudin's Cockatoo (*C. baudinii*), Carnaby's Cockatoo is a hollow-nesting species that favours holes formed only in ancient trees, many which have been lost to logging and land clearing. Further competition for nest sites from the hollow-nesting Kookaburra only serves to exacerbate problems.

Another unfavorable aspect of the Kookaburra colonising within conservation areas is that zones within them are set aside within for tourism and camping. At camp sites in particular, supplementary feeding by visitors may attract more than one group into that area. This "could have a knock-on effect on the local abundance of prey if the kookaburras eye off the odd skink or invertebrate in between the meatball morsels" (Legge, 2004, p. 113); which gives some food for thought.

These examples raise concerns about the presence of Laughing Kookaburra in these important 'Conservation and Protected Resource Areas'. At stake is the maintenance of successful breeding programs to aid the re-population of unique Southwest species. Climate change, associated with increased temperatures and steadily declining rainfalls, and the occasional bushfire are real enough threats already presenting barriers to their continuance. The presence of the Laughing Kookaburra, a proficient hunter, with well-attended broods, in considerable number, spread across much of these areas, presents another major obstacle.

This concludes discussion about the Laughing Kookaburra in relation to the chronological map series, and climate and landscape features of the study area. Discussion now moves toward *Spatial Statistics* associated with the species.

7.9.11 Spatial Statistics:



Map 7.10: *Spatial Statistics*: Laughing Kookaburra
Standard Distance, *Directional Distribution*, *Mean Centre* and *Central Feature*
(All Eras: 1898 – 2007)

There are four *Spatial Statistics* relating to the Laughing Kookaburra: '*Standard Distance*' (□); *Directional Distribution* (□); *Mean Centre* (★) and *Central Feature* (☆) (Map 7.10). The *Standard Distance* statistic measures the extent features are concentrated or dispersed. Here it shows how widespread the dispersal of the species is, with the distribution extending across the south-west corner and spilling into the south-east. The population is concentrated across the Swan Coastal Plain; south to Manjimup, into conservation and farming areas; east to Northam, and south-east past Narrogin, into the Wheatbelt.

The *Directional Distribution* shows that the spread of the species is trending north-west along the coast, into remnant Kwongan bushland. The area recieves moderate annual rainfalls and the extent of urban development is increasing. Whereas inland in this vicinity, rainfall diminishes and there are less settlements. The trend south, south-east, although inland, is in the proximity of townsites surrounded by forests and thickets within high rainfall areas where water and food is plentiful.

The separation of the *Mean Centre* (centre of concentration for a set of features); and the *Central Feature* (most centrally located feature), is probably best explained as the *Mean Centre* representing the centre point of potential spread; and the *Central Feature* displaying the mid-point for the population as it currently stands.

7.9.12 Dispersion of Laughing Kookaburra within the Study Area:

The final aspect of the data analysis relates to patterns in the dispersion of the species. Whilst dispersal within a population does not always change the overall distribution of a species, it does influence patterns of abundance and dissemination within the range i.e. the dispersion of the population. The act of dispersing "allows birds to respond rapidly to local conditions" (Newton, 2003, p. 472). It assists them in relocating away from unfavourable habitat such as areas that are under-resourced or over-crowded. It may also help them sustain a presence in an area where the population is threatened, by promoting reoccupation of previously vacated habitat. It is a critical ecological process that influences population distribution and density.

Dispersion, says Lack (1954), in relation to birds specifically, is a deliberate phenomenon. One whereby individuals of the species do not, or at least rarely, disperse either randomly or uniformly within their environment, particularly when breeding. Rather they select sites that possess optimal carrying capacity for the highest density; where food, especially food for the hatchlings, is plentiful. It is a state, he says, which arises mainly due to the behaviour of first time breeders, which tend to settle in greater number in the more favourable habitats. But only up to a point, after which they will relocate to "a type of habitat less favourable except in being less crowded" (Lack, 1966, p. 299).

However, there are several factors that affect dispersion: some species display 'site fidelity, (refer Chapter 2, page 27); whilst others are philopatric (refer 27). Behaviours such as these potentially limit dispersal distances and cause populations to cluster.

The analyses used to examine dispersion were Moran's I*ndex* and *Average Nearest Neighbour*. For a detailed explanation of the statistics, refer to Chapter 3 (pages 58-59).

The data calculated for Laughing Kookaburra (Table 7.12) exclusive of breeding, returned 'Highly Clustered' values for Era A, 1898-1953; Era B 1954-1980; and Era C 1981-2007. The *Mora*n's Index score increases substantially between Era A and Era B (by 0.49181); which indicates intensification of population clusters. The reduced 'Z Score' suggests a reduction in similarity between the features, which is indicative of the extensive range expansion of the species throughout Era B.

Through Era A, the *Introduction* phase, the liberated populations and their offspring, display clustering around sites in the metropolitan area, within the north-west sector and along the Southwest Peninsula. Whereas, by Era B, the *Establish or Fail* phase, the acclimatised population has dispersed inland beyond the Wheatbelt.

Clustering is evident in the population at localities immediately north of Perth, east, near Northam, on the south-west coast between Margaret River and Augusta, at Albany and to the south-east in the area extending from Donnybrook to Katanning, as well as around Mt Barker.

Table 7.12: Laughing Kookaburra - Moran's I index (Includes Breeding)
(Source: The Present Study)

Laughing Kookaburra: Moran's I index (Includes Breeding)					
Era/Group	Moran's I	**Expected**	**Variance**	***Z- Score***	**Description**
Era_A	0.15999	-0.00433	0.00057	6.86263	Highly Clustered
Era_B	0.65180	-0.00035	0.01578	5.19087	Highly Clustered
Era_C	0.70132	-0.00009	0.00012	64.42006	Highly Clustered
Breeding_Era_A	-0.05586	-0.14286	0.02989	0.50325	Highly Clustered
Breeding_Era_B	0.45252	-0.00610	0.97674	0.46405	Random
Breeding_Era_C	0.78423	-0.00962	0.02695	4.83531	Highly Clustered

Clustering is evident in the population at localities immediately north of Perth, east, near Northam, on the south-west coast between Margaret River and Augusta, at Albany and to the south-east in the area extending from Donnybrook to Katanning, as well as around Mt Barker.

The Moran's I score between Era B and Era C, *Spread or Remain Local* phase, increases, but only marginally (0.04952). This suggests that although the extent of clustering has increased, it is not significant. Of particular note is the substantial increase in the 'Z Score' for the species in this era; indicating that whilst the previous range has contracted somewhat; the population has continued to grow exponentially, creating extremely strong similarity between the calculated features.

By Era C, intense population clusters extend from north of Perth, across the Swan Coastal Plain, to Mandurah, east to Northam, along the Southwest Peninsula from Busselton to Augusta, as well as along the southern coast from Walpole to Albany. There is also some clustering of inland populations around Manjimup and around Katanning.

The results, however, show dissimilarities between groups when calculated in relation to breeding. Whereas both Era A and Era C sightings returned 'Highly Clustered' values, Era B returned 'Random'. There are also notable differences between scores for each era, with the Moran's Index for Era B showing a negative value, and increasing significantly (by 0.72837) to a positive value by Era C. The 'Z Score' for Era C also increased significantly (by 4.33206) to almost ten times that of Era A. This suggests that breeding records during Era A, although displaying clustering, were not limited to some sectors, but were clustered sporadically across an expansive area. Hence the much lower *Z-Score* and reduced similarity between features for that era in comparison to Era C.

Whereas, by Era C, incidences of clustering had increased within specific localities, as evidenced by the closeness of breeding records for the era within the greater-metropolitan area; the central-south and in south-east sectors of the study area.

In terms occurrences of breeding for Era B, the 'Random' value, displays a *Z-Score* mid-way between Era A and Era C, which hints at expansive dispersion, rather than clustering. More-so, it has a lower 'Z'-Score' than Era A, which suggests a reduction in similarity between features i.e. they are across a more expansive area. This is evidenced by the widespread incidences of breeding for the era which occur in the north-west and north-east sectors, in parts of the metropolitan area, the area extending from Donnybrook to Katanning and from Mount Barker, eastward across parts of the Stirling Ranges.

It is a challenge to accept that breeding site selection by the species, given its specific territorial requirements is at all 'Random', especially in consideration of the size and changing landscapes of the study area. This brings to mind, the views of Lack (1966); who postulated that populations do not disperse randomly in any setting, most notably when breeding. But rather, he says, will relocate to "a type of habitat less favourable except in being less crowded" (1966, p. 299).

This suggests that site selection is therefore, not so much a response to random variables, but an indicator of site suitability. Although site selection may calculate as being 'Random', in reality, site selection by Kookaburras in Era B was based on the ecological capacity of sites to produce positive breeding outcomes.

This concludes discussion on Moran's *Index* spatial autocorrelation analysis. The final analysis conducted to assess the internal distribution of the overall population is the *Average Nearest Neighbour* function.

The calculation is based upon measuring the average distance from between each neighbouring feature. If less than the average calculated for a hypothetical random distribution, the features are classified as 'Clustered'; if greater, they are 'Dispersed'. The calculation assumes all features measured are free to locate anywhere within the study area i.e. there are no barriers; and that all features are independent of one another. Results from this statistic are best when the study area is fixed, a condition met by the present study.

Unlike Moran's I*ndex*, the results of *Average Nearest Neighbour* analysis produce the same classifications for each Era (Table 7.13). The data (exclusive of breeding) displays that the highest *Observed Mean Distance* between neighbouring individuals, relate to Era A, 1898-1953, (n=036926). During this Era the population was comprised mainly of liberated birds and a few offspring.

Birds were freed in many areas, extending from the north, north-east sectors of the study area, across the Swan Coastal Plain, south past Mandurah, along the Southwest Peninsula and the Blackwood River, as well as at many localities in-between. The statistics simply reflect the expansive distances between records in for this Era.

Table 7.13: Average Nearest Neighbour - Laughing Kookaburra (Includes Breeding)
(Source: The Present Study)

Laughing Kookaburra *Average Nearest Neighbour* **(Includes Breeding)**					
Species/Group	***Observed Mean Distance***	**Expected Mean Distance**	**Nearest Neighbour Ratio**	***Z Score***	**Distribution**
Era_A	0.036926	0.140518	0.262786	-0.214817	Clustered
Era_B	0.010512	0.056250	0.186872	-83.350104	Clustered
Era_	0.004500	0.025993	0.173138	-166.567600	Clustered
Breeding_Era_A	0.130816	0.301504	0.433879	-6.587811	Clustered
Breeding_Era_B	0.091779	0.187688	0.489000	-12.557232	Clustered
Breeding_Era_C	0.084120	0.153681	0.547365	-8.873068	Clustered

By Era B, 1954-1980, the *Observed Mean Distance* between records had reduced by more than one-third (to 0.010512). The statistic reflects the exponential increase in the population for this era. Whereas the population of Era A was concentrated along the coast, by Era B, it had established widespread inland populations extending into the Central and Southern Wheatbelt. The distance between groups reduced as the population increased.

The *Observed Mean Distance* statistic for Era C, 1981-2007 is significantly less than those calculated for the previous Eras (*n*=0 .004500) at one eighth that of Era A, and half that of Era B. Statistically this gives an indication of the extent of population growth for this period. Population clusters have expanded and display denser concentrations in a number of sectors. The most evident appear around the metropolitan area and beyond to agricultural districts to the north and north-east of Perth, as well as the Southwest Peninsula, the coast between Walpole and Albany, and inland around Mount Barker and surrounds.

By Era C, the number of sightings within the interior, from Gingin to Jerramungup had increased which contributed to the reduction in the 'Observed Means Distance' statistic for this Era. Other than the effects of increased population densities, a minor range contraction along the eastern margin, probably due to Era B populations failing to establish permanent populations in these low rainfall areas, combined to further reduce the statistic.

Similarly, in terms of breeding, the *Average Nearest Neighbour* statistic reduces for each era. In Era A, the statistic is at its highest (*n*=0.130816). By Era B this has reduced by approximately one-third (to *n*=0.091779). This is the most significant reduction of the statistic between eras; with the figure for Era C only marginally less (at *n*=0.084120). This confirms that the species was taking up space within the established geographic range, and settling territories suitable to breeding.

This steady reduction in the statistic can be limited with what was occurring spatially; with breeding incidences in Era A widely spread out across the study area; interspersed across the north, north-east sector, and with the majority of breeding occurring in proximity to the South Perth release site. By Era B, breeding incidences in the northern sector had reduced nominally, those in the metropolitan area radiate further out across more suburbs; and breeding is occurring in the south-east, in parts of the Wheatbelt. Breeding is also recorded around Mt Barker and Manjimup.

Whereas, by Era C, breeding is focussed mainly in two juxtaposed regions: northernmost in the greater metropolitan area; and southernmost, in the area from Walpole to Albany and inland to Mount Barker. Breeding success within urban areas is probably enhanced by increased food availability (prey foods supplemented by backyard feeding). Albany, although a rural town, is a major regional centre and has a considerable urbanscape; and the outlying districts, toward Walpole support forested areas, and toward Mount Barker, cultivated farmlands interspersed with remnant woodlands, habitats suited to raising broods.

In relation to the functional territory type maintained by of Laughing Kookaburra, it is characteristic of a typical 'Type A' species (as per Hinde, 1956) (refer Chapter 2, page 31): as it establishes an 'all-purpose' territory able to resource roosting, courtship, mating, nesting and feeding. It is likely the territory size only reduces when resources are abundant (Stenger, 1958) to avoid an energy deficit arising from maintaining too larger territory when all that is required can be found close-by; or alternately, in response to conditions becoming over-crowded.

This concludes discussion on related to Laughing Kookaburra. A summary of the key points identified are now presented.

7.10 Conclusion:

The Laughing Kookaburra complies with the 'Invasibility Rules' set down by Brown (1989) to some extent (refer Chapter 2, page 18). In relation to 'Rule 1', which recognises that 'isolated environments', with 'low diversity' of native species are 'differentially susceptible to invasion'; the Kookaburra has proved such an optimal invader it has widely colonised areas within a renowned global 'biodiversity hotspot' recognised for the richness of its biota. It has not only invaded the woodlands, but spilled into adjacent areas cultivated for agriculture, as well as nearby towns.

As for 'Rule 2', the Kookaburra is indigenous to the Australian continent. It occupies 'non-isolated habitats' comprised of "woodland, forest clearings, [and] timbered watercourses" (Pizzey & Knight, 1997, p. 316). It also inhabits parks, gardens, orchards and farmlands in its native range from east of the Eyre Peninsula, across Victoria, into all but the arid interior of New South Wales and Queensland. As for 'Rule 3', the species has adapted most successfully in areas where 'the physical environment between the source and target areas' show similarities.

In relation to ‘Rule 4’, within the study area the Kookaburra has not occupied an ecological niche ‘not utilised by native species’, but has settled habitats essential to the preservation of at risk endemic species. This may cause a narrowing of their niche, or niche overlap, resulting in resource limitations that may have an adverse effect on population levels. Finally, in terms of ‘Rule 5’, that successful biological invaders ‘inhabit disturbed environments and have a history of close association with humans and settling man-modified habitats’, the Kookaburra has a reputation that it can “adapt to landscape modification by humans better than any other species of bird” (Legge, 2004, p. 112).

Another construct investigated is that of territory. It has been documented that bigger birds defend bigger territories (as per Hinde, 1956). An idea lent further support from T.W. Schoener (1968b), who believed “territory size was directly proportional to the bird’s body weight, i.e. larger species defended larger areas” (Perrins & Birkhead, 1983, p. 12). This helps contextualise why Kookaburras need sizeable territories, and explain the extensive geographical range it occupies. The increasing densities of sightings throughout each phase indicate that the largest kingfisher has established a network of territories, of varying sizes, to meet the ecological needs required to ensure its continued existence. The Kookaburra maintains a permanent territory that provides for all feeding, breeding and roosting needs.

In summary, the Laughing Kookaburra, or ‘Gugubarra’, as named by the Wiradjuri people of New South Wales, is a highly specialised avian predator. It possesses extraordinary bill and neck strength to offset the weakness of the feet caused by syndactyly. It has binocular vision to aid in locating prey and produces complex vocalisations related to its social behaviour. Free-ranging Kookaburras are also heterothermic, which makes it able to ‘self-warm’ and therefore, not dependent on the sun to reach ambient temperature. This feature, coupled with the ability of the species to enter a state of torpor when roosting i.e. to lower body temperature significantly (by about 6°C) to conserve energy, gives it a major energy advantage over most other species. As it is not dependent on the sun to rewarm or remain warm, it is able to hunt in the pre-dawn and at dusk, which affords it a further advantage.

Although belonging to the kingfisher family, it does not eat mainly fish, although some aquatic prey items, such as small fish and crustaceans are eaten. It consumes mainly invertebrates, insects, and small vertebrate prey items such as lizards, snakes frogs, birds, rodents and rabbits. To secure larger prey it will hunt cooperatively with members of the same group to repeatedly assault prey, usually by dropping it from some height, until it is immobile.

Hunting is not the only cooperative activity undertaken, as the species lives in hierarchical family groups that undertake year-round territorial defence and brood rearing. The hierarchy within each family group is regimented by age and sex: the adult breeding male is dominant over all male auxilaries, older auxilaries dominate younger siblings, breeding females dominate female auxilaries. Fledglings are subordinate to all group members of the same sex. The lesser roles of auxilaries is a strategy to supress breeding.

The defence display is initiated by the dominant male which occupies a defence perch at the territory boundary. His call is directed towards the neighbouring group, and the chorus is picked up by others of the group. The chorus is returned by neighbours in defence of their territory. The complex vocalisation of the species, as well as a tool for territorial defence, is a means of identifying members of the same group to each other, and differentiating those that belong to other groups.

Defence calling is accentuated with complex flight displays involving all members of the group. Like the chorus song, the flight displays are initiated by the dominant male then repeated by others of the group for up to half an hour. Other than being integral to territorial defence and inter-intra group identification, the chorus song also strengthens the social bond between individuals of a group, and relieves nervous tension. This last point though is dismissed as a 'real function' by some others.

There are distinct elements to the song, however consensus is lacking as to how many. However, it is agreed that there are distinct diurnal patterns of song, with the number of choruses peaking at dawn and dusk: the more group members present (at these times), the greater the frequency of songs. The responses to songs of members of the same group assist in establishing and maintaining group hierarchy. Whereas singing between a breeding pair can represent an attempt by the male to protect his own female, or an attempt to attract other females; whereas the female sings to "monopolise the parental investment of her mate.

At breeding time, mature non-breeders, the multiple offspring of previous clutches, that remain with the group, act as a 'helper' or 'auxiliary' or 'supernumerary' to aid in incubation and to care for the newly hatched nestlings and the surviving fledglings. The Kookaburra engages in siblicide (whereby the weakest of the brood is killed by its siblings). It is more frequent in broods that number more than two; with the third chick the most usual to succumb. Nestlings are extremely aggressive toward each other from the point of hatching, although the aggression decreases as they age.

Generally groups with more female helpers have a male biased clutch and fledgling sex ratio; groups without female helpers produce a female biased clutch and fledgling sex ratio. In terms of the sex in relation to hatching order, two-thirds of first hatched are male; two-thirds of second hatched are female; with the sex ratio of third hatched nestlings even. First hatched males have a weight gain advantage over later hatched females. All these social activities can be seen as offering advantages in colonising a new environment.

The most successful introductions of Kookaburras however, have been within Australia, with populations translocated to other countries either failing, or establishing only localised populations. Plans to acclimatise them in England were never actioned, although individual birds were reported to be living at the London Zoological Gardens, and a private home in Sussex. An attempt to introduce the species to Fiji failed, although, it is mentioned later in relation to Viti Levu by visiting ornithologists (Blackburn, 1971).

It was first introduced to New Zealand, *circa* 1860s, near Kawau. Further introductions were made by a number of acclimatisation societies between 1864 and 1879. However the population has remained limited to Kawau and any present on the mainland originated from there. It was reported later that the species had become established around North Auckland, from Whangarei to the Waitakere Ranges, as well as Kawau Island. Recent estimates put the population at 300-500 birds in Kawau Island and parts of the mainland.

The Kookaburra was also released on various islands off South Australia and Tasmania. It is now widespread across Tasmania and some of its islands such as Flinders and Waterhouse Islands. It has also established a permanent population on Kangaroo Island. However it was never as successful in these other destinations as it was in the study area.

From when it was first released in Western Australia, *circa* 1896-97, the species soon colonised and was breeding in the wild. In the localities of Warren and Hamel, the species was so abundant within its first decade after release that it was hoped the demand for more of the birds in other localities could be met by using these locally bred birds.

Its ability to adapt to landscape modification better than any other species of bird has been recognised. It is now prolific throughout the greater metropolitan area and in many regional towns. It has a wide ranging distribution throughout forest conservation areas in the south-west of the study area, and has established permanent populations across dryland agricultural areas. The geographical distribution of the species was at its greatest in Era B, 1952-1980, but a range contraction on the eastern boundary occurred in Era C, 1981-2007. Despite this however, it has become far more prolific and more frequently sighted.

The depiction of the data for Era C shows the concentration of the species around the metropolitan area. These dense urban populations could be attributed to food availability due to 'backyard birders' feeding them. This activity should be discouraged to avert dependency by the species on food from this source and avoid dietary deficiencies that may develop if natural foods are excluded from the diet. Hand-fed Kookaburras may also become demanding and damage property or hurt themselves seeking food from this source.

The species has also become common around the area on the south, south-east coast between Walpole, Denmark, Albany and Mount Barker. The first two localities are situated in close proximity to conservation areas that support relatively undisturbed plant communities and high levels of biodiversity, but have still proved invasible by Kookaburra. The latter two localities are situated within farming districts, but are not so extensively cleared of woodland habitat as to deter the Kookaburra.

The extent of sightings of the Kookaburra in conservation areas over a prolonged period (spanning the duration of the period covered in the study from 1898-2007), is of mild concern. Whist Legge (2004) states that no definitive research links the species to declining population rates of local native species, no dedicated research into this has been identified.

What is known is that the Kookaburra is prolific throughout areas that support at risk endemic animal species, with which they share a similar feeding and breeding ecology. As a hollow-nesting species it is in direct competition with Carnaby's Black Cockatoo, Baudin's Cockatoo and the Forest Red-tailed Black Cockatoo. As a species that is able to subsist on a varied diet of invertebrates, insects, frogs, small reptiles and mammals, it competes with the rare (once thought extinct), Noisy Scrub-bird, as well as the Red-tailed and Brush-tailed Phascogale. Other than competing for food and nesting resources with these native species, its di*et al*so has the potential to threaten existing populations of millipedes, spiders, frogs, freshwater snails, and rare freshwater crustaceans already in decline.

Following failed introductions in other regions and a shortage in the supply of translocated specimens, the acclimatisation of the Laughing Kookaburra into Southwestern Australia became an outstanding 'success'. Within two years of its release, in the initial phase of the invasion process, the species was already "thriving and breeding well" (Le Souëf, 1902). Its physical size and biological adaptations, and ability to survive in human-modified habitats, in close proximity to people, ensured its survival.

There is little doubt the adaptive traits of the species helped it adjust to the adopted environment, which already shared many similarities to that from which it had come. Its ability to produce complex songs and broadcast inter-specific and inter-group warnings in the defence of territory, as well as develop intra-specific alliances helped it to establish and maintain territorial boundaries. Its social behaviour, i.e. living as an extended family group, also enabled it to hunt large prey items and undertake cooperative brood rearing.

The species also engages in siblicide, another ingrained response designed to maximise nestling survival and fledging success. Newly fledged juveniles engage in play to develop hunting skills, to ready them as keen-eyed hunters. As well as its possessing binocular vision, the bill size and strong neck allow the species to capture and dispose of prey efficiently. The species can also hunt earlier and later in the day than its competitors, as it is heterothermic i.e. able to self- warm to ambient temperature. Also, the Kookaburra can also enter torpor i.e. reduce its body temperature overnight and expend less energy whilst roosting, giving the species another energy advantage over its competitors.

These combined features and traits have in effect, fashioned an optimal, iconic invader. The Laughing Kookaburra has shown it is capable of colonising not just disturbed habitats, but pristine conservation areas. The earlier misgivings of some, so hastily set aside, may finally prove defensible.

8 CONCLUSION, RETROSPECT, AND PROSPECTS

8.1 Review of Hypothesis and Research Questions:

There were several aims to the present study. Fundamental to their implementation was the compilation of a comprehensive dataset consisting of historical sightings records, limited to the Southwest region of Western Australia, and pertaining to the focus species which included: the Australian White Ibis (*Threskiornis molucca*), Spotted Dove (*Streptopelia chinensis*), Laughing Dove (*S. senegalensis*), and Laughing Kookaburra (*Dacelo novaeguineae*). To meet this objective, information was requested from a number of government agencies, organisations and individuals.

Digital data was subsequently supplied by the Commonwealth Government Australian Bird and Bat Banding Scheme; as well as DAFWA, although records from this source were excluded as it was not inclusive of all the focus species. Digital data was provided by Birdlife Australia (formerly Birds Australia) in the form of *The Atlas of Australian Birds* (Blakers *et al.*, 1984), *The New Atlas of Australian Birds* (Barrett *et al.*, 2003), *Birdata*, online atlas (Silcocks, 2011) and the Nest Record Scheme.

Records were also sought from ornithologists of professional repute. The most historic records, stored on microfiches, and compiled by members of the Royal Australasian Ornithologists Union (which later became Birds Australia) were transcribed by hand and then digitised. Similarly, records from the Storr-Johnstone databank, compiled by the former Curator for Birds, Glenn Storr, and the present Curator, Ron Johnstone, at the Western Australian Museum, and including contributions from others observers, were converted from hand-written notes to digitised form.

The data, which were compiled using a number of different methods and styles of recording, were entered into an MS Excel spreadsheet file, whereupon the entries were standardised and updated to reflect the current datum system. These records were then exported to MS Access database file where missing decimal coordinates, integral to the Geographic Information Systems (GIS) analysis, were imported. After a series of checks and corrections, the data were imported in to *ArcView 9.2* programme (ESRI, 2007) for analysis. The data were segregated into three eras, Era A, 1898-1953, *Introduction, Death or Captivity*; Era B, 1954-1980, *Establish or Fail*; and Era C, *Spread or Remain Local*, 1981-2007 to allow for comparisons between temporal 'snapshots' and to fit the parameters of the theoretical concept of the *Invasion Process Model* as prescribed by Lockwood *et al.* (2007).

The analyses produced map series specific to each species depicting spatial and chronological patterns of dispersal subsequent to their arrival in the study area, and relating them to geographic and anthropogenic features, e.g. climate and landuse.

This provided a means of identifying some similarities and dissimilarities between the colonisation strategies adopted by each arising from differences in their biology, and how each adapted to the physical environment and ecological conditions of the adopted landscape.

Overall the study design was intended to examine the data as a means of validating or rendering invalid the following hypothesis that:

Different colonising avian species have adopted different colonisation strategies reflecting their own biology, in relation to the physical and ecological environment of the colonised landscape.

To investigate the hypothesis, five research questions were devised, which defined the scope of the research and were fundamental to the methodology developed. Each question was investigated fully and a number of conclusions were identified, as discussed below:

Research Question 1: What variations in spatial-temporal patterns of spread emerge when Geographic Information Systems analysis is applied to historical sightings data for each of the focus species? This question asks whether variations in spatial-temporal patterns of spread amongst the focus species were evident. The resultant GIS analyses and map series showed distinct differences in patterns of spread over space, and time. Each species displayed variations in the extent of colonisation, influenced by how they arrived to the study area.

The immigrant species, Australian White Ibis, was the most widely dispersed and least recorded coloniser during Era A. It was also the latest arrival to the study area, having only reached the Southwest in 1952 whilst the others were present post 1898. Sightings were limited to just a few localities in the south-west portion of the study area: near the coast at Bunbury and Busselton, and further inland around the townsites of Picton and Coolup.

By Era B, the presence of the species had grown and it was clearly advanced through the second stage of the invasion process. Breeding was occurring in the wild at several sites. The population distribution was mainly linearly along the coast, although it was also present inland, probably at sites of natural drainage (lakes, wetlands) or at farm dams.

By the close of Era C, the distribution of the species extended to the study area boundaries. To the south-east there was also an incursion in the vicinity of Mount Barker, which is situated within pastured areas well suited to the species. However, the greatest increase in the presence of the species is along coastal urban areas. The distribution has not remained localised, but is continuing to build and disperse. It has shown it is a successful biological invader and a true urban usurper.

The *Streptopelia* doves, Spotted Dove and Laughing Dove, however, immediately presented as contrasting colonisers, despite being released at around the same time and under similar conditions. Within Era A, each developed contrasting patterns of settlement arising from dissimilarities in the colonisation strategies utilised by each in the adopted landscape.

There were some sightings for the Spotted Dove in rural areas in Era A, within the north-east and south-west sectors, related to release sites. However, around the metropolitan area, after having breeched the 'bush belt' of the Darling Scarp, the species did not continue its push inland. Its spread contracted in Era B and the population became concentrated in urban areas, and to the urban-rural fringe, bounded to the east by the Darling Ranges. Throughout Era B, its rural spread continued to decrease with fewer sightings for the species in the north-west and south-east sectors of the study area. However, sightings across the greater-metropolitan areas became more concentrated. By Era B, breeding had also contracted to mainly within the metropolitan area, with breeding incidences in the north-east sector reduced. By the close of Era C, there were fewer sightings again of the species recorded in rural areas. The build-up of sightings in urban areas had become denser, and less openly spaced. Breeding remained focussed inside metropolitan precincts.

Whereas, during Era A, the Laughing Dove, as well as dispersing rapidly across the metropolitan area traversed the Darling Scarp and spread eastward into the interior. During Era B, its presence across the inland hinterlands continued to increase, especially to the north-east, east and south-east, although incidences of breeding reduced in the north-east sector. The urban population also increased substantially during this period. In Era C, the species experienced a range contraction along the eastern boundary of the study area. Whereas around the metropolitan area, sightings of the species continued to increase, eventually extending beyond those of Era B. By Era C breeding in rural areas had declined further and was concentrated in the metropolitan area.

Whilst the Spotted Dove population was concentrated in areas up to 100km of the metropolitan region, the Laughing Dove settled extensively in some rural areas to the north-east, east, and south-east. However it did not become established in the south-west sector.

The most successful colonising species of all the focus species was the Laughing Kookaburra. It probably had an advantage from the outset, as it was liberated in hundreds, at the greatest number of localities, and in the most widely dispersed locations. It was also coming into an environment not unlike that from which it had probably been taken: consisting mainly of forests and heath, as well as urban areas to which it is remarkably suited.

The mainly coastal distribution of the species in Era A extends from the metropolitan area, south to the Southwest Peninsula. After which it becomes sporadic, with sightings concentrated in the south-east around Walpole, Denmark and Albany. It was also recorded inland in forested around Manjimup, and as far as Katanning. There were also some sightings in the north-east.

By Era B, whilst the urban coastal population has become denser, the greatest change in the distributions between the Era A and Era B (populations) is the extent of coverage: which extends across most of the study area by Era B. Although its presence along the eastern boundary, in areas of low annual rainfall thins out as it advances towards the east.

By Era C the urban coastal populations builds-up from the northern end of the Swan Coastal Plain, to south-east of Albany and the proliferation of sightings around the greater metropolitan area has intensified further. The area between Albany and Mount Barker, in the south-east also displays a much heavier concentration of sightings. This concludes the summary on differences in the spatial-temporal patterns of spread of the species. This leads to discussion of the second research question.

Research Question 2: How are these patterns associated with the ecological needs of the species? In relation to the White Ibis, the widely dispersed, but limited population of Era A, had by Era B, become concentrated around areas of human habitation. The species flexible feeding ecology allowed it to integrate alternative food sources to those found at traditional sites into its diet. It became an opportunistic scavenger, fossicking at bins and refuse sites, and places where food was served or prepared. In rural areas it colonised dairying districts of the south-west, an environment dominated by irrigated pasturelands, interspersed with wetlands and swamps; providing habitats well suited to the species. The White Ibis may also have benefited from the release of several types of exotic Scarabaeidae beetles into the region by the CSIRO in an attempt to manage accumulating dung. Its increased presence in Era C, in coastal urban areas, and inland, in farming districts, confirms its ecological adaptability to man-modified habitats.

As stated previously, the Spotted Dove and Laughing Dove followed very different colonisation strategies, resulting in contrasted distributions. The Spotted Dove remained localised within 100km (approximately) of urban areas, possibly as it could not tolerate the dry conditions inland. However, its distribution in the study area presents a similar scenario to its introduced populations in eastern Australia, which are also localised in urban areas, despite the moister conditions of the countryside.

This suggests that it is more than just a moisture barrier that prevents it from settling rural areas. Rather, the main colonisation strategy adopted by the species is to utilise ecological resources characteristic of areas of human habitation. It has been able to incorporate exotic seeded grasses, sourced from gardens, roadside verges and urban wastelands, as well as domestic animal feed and bread into its diet. It also accesses water from artificial sources, such as bird baths and ornamental ponds, and it has also adapted its breeding ecology to nest in built structures (and plant pots) and is clearly habituated to the presence of people nearby.

Whereas, the smaller Laughing Dove was able to tolerate the dry inland conditions and utilised supplementary water supplies to survive. The species subsisted well enough to breed, on the produce related to wheat and other grain growing enterprises and the practices linked to the harvest and transport of these crops. Not only did it utilise the field produce of these regions as a food source, it made use of grain spilled during processing and transport, that lay alongside rural road and rail routes.

Like the Spotted Dove it also settled across the metropolitan area, as well as in country towns, often those with grain storage and transport facilities. It also utilised ecological resources common to areas of human habitation e.g. grasses, and animal feed. It adapted to breeding in the urban environment, nesting in built structures, and in verge-side vegetation close to vehicular and pedestrian traffic. It has become habituated to living in close proximity to people in order to utilise the ecological advantages that accompany it.

The rapid and widespread dispersal of the Laughing Kookaburra throughout the study area attests to its flexible ecology, which is aided further by physical adaptations specific to the species that make it a proficient hunter e.g. binocular vision, large bill size and exceptional neck strength. It also (usually) lives in family groups that allow for cooperative territory maintenance, hunting and brood rearing. Its garrulous nature and song-chorus have also made it popular with 'backyard birders' who lure it with food.

Wild Kookaburras have further ecological advantages over most other species, as they are heterothermic (able to self-warm to ambient temperature) and can enter torpor (reduce body temperature whilst roosting). This decreases their reliance on solar-radiation to rewarm and so they are able to hunt in the pre-dawn and dusk, longer than most other diurnal birds. They also have an energy advantage over other species as less energy is expended to maintain warmth.

Of all of the target species, its diet is the most varied, it being able to subsist on invertebrate prey, insects and beetles, as well as snakes, lizards and frogs. It is also capable of taking large prey items such as small birds, rabbits and rodents (mainly when smaller prey items are in short supply). Sometimes the bigger prey items, such as snakes and large lizards, are hunted and killed cooperatively, and shared amongst members of the same family group.

It has also adapted its breeding ecology to man-modified habitats, by nesting in hollows other than those in trees, e.g. a depression in a rock quarry wall, in built structures, such as a verandah, or inside a wall cavity. It also displays physical and behavioural adaptations designed to enhance breeding success. The Kookaburra young hatch with a hooked beak to aid siblicide, and in multiple broods, first hatched nestlings will kill a weaker nestling to minimise its own starvation risk. The beak-hook grows out as it develops.

Brood hatching is also highly non-random, with the social structure of the family group influencing brood structure: i.e. when there are more female auxiliaries, there is greater male clutch bias and fledgling sex ratio; whereas, when there are more male auxiliaries (unassisted pairs or male only helpers); there is greater female clutch bias and fledgling sex ratio. Nestling sex in relation to hatching order is also quite ordered, with two-thirds first hatched male; two-thirds of second hatched, female (with no difference in the sex ratio of third hatched nestlings). This is an adaptive strategy that allows earlier hatched, smaller sized male nestlings, to obtain a weight gain advantage over later hatched, larger sized female nestlings.

The flexibility of the species feeding and breeding ecology, in combination with its adaptive physical attributes and social behaviour remove most geographic and anthropogenic barriers to spread within the Southwest. The main limiting factor is moisture, for whilst it thrives in forested, cultivated and urban habitats, its sporadic presence along the eastern fringes of the study area corresponds to areas of low annual rainfall, which retain few reliable water sources, a factor essential in territory selection by the species. This concludes discussion relating to this query. Discussion now moves toward the third research question.

Research Question 3: What roles do geographic factors, e.g. climate features and biotic distributions, influence dispersal? This question relates to the role of geographic factors i.e. climate features and biotic distributions in influencing dispersal. A number of conclusions come from this enquiry. Overall, climate, i.e. temperature and rainfall, did not appear to be the determinate factor in inhibiting or promoting spread, or in breeding by the focus species. That is not to say, it did not exert some influence, as the sparse populations of each species along eastern boundary, which corresponds to an area of low rainfall, attests.

Evidence of breeding by White Ibis in areas of low rainfall indicates that it is not the amount of rainfall in itself which influences breeding site selection: it confirms the opinion of Carrick, (1962), that it is the availability of a suitably flooded area. Although this is not the only factor that influences breeding or roosting site selection by the species. Particular vegetation types are favoured, including *Muehlenbeckia* spp; *Eleocharis* spp and *Typha* spp.

The presence of the focus species, other than the Spotted Dove, in each climate zone, can be contextualised in relation to other factors than climate. The abundance of the Spotted Dove around the greater metropolitan area was a feature common to all the focus species. Their success probably arises from the ecological advantages of each species, as described earlier.

In term of the influence of biotic distributions on the dispersal of the focus species, movement was not so much influenced by the presence of the vegetation, as by its absence. The movement of several of the focus species into cultivated lands was aided by the broadscale removal of native vegetation to make way for pastures and cropping.

To the north-east, east and south-east extensive tracts were cleared for dryland agriculture: the proteaceous heaths and scrub-heaths of the Kwongan, along with the Wandoo woodlands of the Avon Valley, and the scrub of the Mallee and heathlands of the Esperance Plains were decimated. Woodlands of the south-west were also removed to create pasture for the dairy production and orchards. The dense ground cover of these plant communities that may have once acted as a barrier to spread of the focus species was removed.

This was especially important in relation to the Laughing Dove which spread unhindered into the interior for hundreds of kilometres. It passed through areas of remnant bushland via transport route-ways e.g. roads and railways built to service these agricultural areas. However, it could not get a hold in the south-west, an area dominated by sclerophyll forest in a region too wet for conversion to dryland cropping.

The south-west corner of the study area is an area renowned for its biodiversity, and possesses extensive tracts of Jarrah, Karri, Tuart, and Tingle forests, mostly contained within protected areas. Although timber was harvested, and some lands cleared for horticulture, dairy and cattle farming, it remains dominated by tall timbers within an understorey which has only proved invasible to the predominantly ground-foraging, seed eating Laughing Dove.

Another possible biotic deterrent to the spread of the Laughing Dove into the south-west forests and the Kwongan heathlands of the north-east is the occurrence of a noxious tribe of plants, *Gastrolobium* spp. Although most indigenous birds and animals are resistant to its properties or have learned not feed on it, or ingest only small amounts of it, the exotic dove may have ingested the seed and fallen to its poison.

Whilst the bushland to the north-east and south-west presented a barrier to spread for the Laughing Dove, it did not deter the Laughing Kookaburra. Rather, the environment seems particularly well-suited to it, especially the Eucalypt forests of the south-west. Although it feeds on species that live close to, or on the ground, it not a ground-dwelling species, and is capable of strong flight. The species-rich forests harbour most, if not all, prey items incorporated into its diet, which it varies depending on what prey is available, and in what proximity. The forests also provide suitable and plentiful nesting hollows. They are also situated in the highest rainfall zones, and are fed by several permanent rivers, so water is accessible, an essential territorial element for the Kookaburra. The south-west forests also resemble the habitat the species occupies in its historic range within Southeastern Australia. This concludes discussion on the third research question.

Research Question 4: How have anthropogenic factors, e.g. human activities and landuse, influenced the distributions? This query relates to how human activities and landuse influenced the distributions of the focus species. This has already been answered to some extent. Examples already provided include the utilisation of domestic gardens and parklands by White Ibis for foraging, as well as it eating from bins and at refuse sites. The other landuse aspect addressed in the case-study was the risk of aircraft strike by Ibis.

Other examples already cited include the incorporation of alternative food sources into the diet by Laughing Dove and Spotted Dove, including the exotic species of crop-seed and grasses used in agriculture and horticulture, as well as domestic animal feed and bread. They have also adapted their breeding regime to include nesting in built structures, like patios and plant-pots and in close proximity to pedestrian and vehicular traffic in verge-side vegetation.

These examples relate to the utilisation of urban habitat by the focus species. However, the setting aside of natural bushland areas for conservation, is the landuse factor which has most significantly benefited the Laughing Kookaburra, having thrived in the ‘Protected Resource’ areas preserving the south-west forests. However, the retention of these areas for this purpose has proven an insurmountable barrier to spread to the Laughing Dove, which although present close to the periphery, has failed to move beyond.

However, the clearest example of the influence of anthropogenic factors on the distributions of the focus species pertains to the spread of the Laughing Dove into grain producing districts. Its dispersal across the Wheatbelt occurred as a consequence of the species incorporating the grains produced into its feeding ecology. This colonisation strategy was aided by the removal of botanic barriers to spread through broadscale clearing of native vegetation. The resultant habitat loss as a result of this practice also significantly reduced regional biodiversity, increasing the 'invasibility' of the environment.

Remnant areas of bushland were not an effective barrier to spread either, as transport routes built to service the agricultural industry in these areas provided access into outlying districts. When steam locomotives were in service, storage dams were built to service them. Although diesel power superseded steam, the dams remained, and acted as a supplementary water supply in these areas, along with farm dams and homestead water supplies. Other than access, transport infrastructure also provided access to a new food source along the road and railway systems. The Laughing Dove learned to forage alongside these routes, accelerating its advance into new localities.

Also the system of planting, harvesting, processing and transporting grain changed. The use of motorised equipment and technological advances decreased spillage and waste, both on the farm and during transport. Less grain was spilled during planting. Less was left behind during harvest. The practices of auguring produce at the harvest site into fibrous bags, that were often overfilled, poorly sealed, then stacked onto open wagons for transport, were superseded by bulk-handling methods. Produce was augured directly into large, enclosed containers and transported to a silo for storage prior to being re-directed, by rail or road for shipping. From the silo it was again augured into enclosed trailers or wagons.

These changes reduced the extent of food availability, which is reflected in a range contraction. The number and extent of Era B sightings fell-back by Era C, most notably along the eastern-most boundary.

Food sources became available only in towns, mainly those with storage silos. Whilst the advent of technologies to improve yield, production and transport, were of such a magnitude to alter the distribution of the population, they did not rout the population. As by the time the changes were wrought, the Laughing Dove was well established and it continued to maintain a widespread presence, despite the changed ecological conditions. This leads to discussion of the final research question.

Research Question 5: Do the focus species have a history of colonising other regions within Australia or other countries? The final research question relates to the status of the focus species in other parts of Australia and the world. The study identified that several of the focus species have either been introduced to, or immigrated from their historic range into other places in Australia. It also identified that several taxonomically related species have a history of continental spread outside of Australia, especially in association to areas of human habitation.

Within Australia, the Australian White Ibis has experienced a range shift from traditional inland sites into coastal urban areas, escaping drought conditions. There are concerns amongst conservationists that inland breeding populations are decreasing to critical levels. Also, that the eggs and embryos of urban ibis contain pesticide contaminants. The range shifts have occurred in Victoria, New South Wales and Queensland. Problems arising from the birds colonising in urban areas are mainly associated with noise and excessive defecation over buildings and vegetation. Increasing numbers are foraging at refuse sites, and scavenging in public meeting areas and entertainment precincts. This is particularly problematic as the species harbours pathogens harmful to humans, such as *Salmonella* spp.

Outside Australia, the Sacred, or African Ibis (*T. aethiopicus*), is widespread and numerous throughout sub-Saharan Africa and is present in parts of Egypt, and southern Iraq. There is also a small introduced population in United Arab Emirates and Kuwait. In Europe, introduced populations, breeding from zoo escapees, are located in Spain, Italy, France and the Canary Islands. Its predation on other birds has made it unpopular with conservationists. In Spain, Italy and the Canary Islands it is restricted to a few sites, but it in France, has spread into Brittany, Normandy, and across western and eastern France. Whilst the majority of birds utilise swamps and marshes, and artificial lakes, others have moved into rubbish dumps to forage. They have been observed preying on Sandwich, Black, Whiskered and Common Tern, Mallard, Black-winged Stilt, Cattle and Little Egret. Within the study area, its relative, White Ibis, co-exists with related prey species at Ramsar listed wetland sites.

In relation to the *Streptopelia* doves, the study area is the only place that both coexist, despite attempts to acclimatise both in a number of places. The Spotted Dove was first translocated into Victoria from its China and Indo-Malaysian origins in the 1860s. It spread to Sydney by 1898, Brisbane by 1913, and Townsville (far north Queensland) by 1926. Later sightings in Cairns and Innisfail were thought related to incursions of "almost pure *tigrina*" (Blakers *et al.*, 1984, p. 222), which differ from other Australian *Streptopelia* populations which are *S. chinensis* and *S. tigrina* hybrids.

It was also introduced to Adelaide, eventually traversing ocean and desert to settle on Kangaroo Island and the Eyre Peninsula, although its main populations remained limited to within (approximately) 100km of the city. Similarly in Victoria, populations remained within (approximately) 160km of the city; in New South Wales, it remained common around Sydney and to larger coastal towns, but failed to settle rural areas. Similarly, in Tasmania it established only limited coastal populations around Hobart and Launceston and failed to colonise rural areas. It has colonised parts of the Northern Territory, including Alice Springs.

Where it is present, it is viewed as a minor pest due to its habit of scavenging, fouling surfaces and buildings, pilfering poultry feed, spreading stickfast flea and damaging nursery plants. In Victoria and South Australia, it has become so abundant it has excluded populations of native Peaceful Dove (*Geopelia striata*) (Pizzey & Knight, 1997).

The Laughing Dove, although introduced to other regions in Australia, including Sydney, Toowoomba, South Australia and Queensland, failed to establish permanent populations and its presence in these localities remains patchy. In New South Wales and Queensland, it initially colonised well, but its numbers quickly declined, possibly due to competitive exclusion by another introduced species, Common Myna (*Acridotheres tristis*). The introduction of the species to South Australia and its failure to colonise widely has been linked to ecological competition with Common Starling (*Sturnus vulgaris*) (Kitching, 1986).

Outside Australia, the native distribution of the Spotted Dove takes in southern Asia, from north-eastern China, Taiwan, Hainan, west to India and Pakistan and south to Burma, Sri Lanka, Sumatra, to Malay Peninsula, Java, Palawan, Borneo and the Lesser Sunda Islands. The origins of the Laughing Dove are cross-continental, extending across Africa and Asia, taking in São Tomé Island, southern Africa, Israel, Jordan, the Arabian Peninsula, Afghanistan, Turkey, Iran, India and Pakistan, far north-west China, Socotra Island and Andaman Islands.

Both species, but especially the Spotted Dove, which is a popular aviculture species, have been introduced into many countries, through acclimatisation, or as a result of the release (or escape) of captive birds (i.e. Fiji, Hawaii and the mainland of the United States). The Laughing Dove has been a highly successful coloniser, especially around areas of human habitation. In Africa, where it originates, in some areas, it is considered a pest due to its habits.

The historical distribution of the Laughing Kookaburra within Australia extends across eastern Australia from Cape York Peninsula, south and west to the southern Eyre Peninsula. As well as in Western Australia, it was introduced to Kangaroo, Flinders and Waterhouse Islands, and Tasmania. It has colonised widely there and is well established across most of the island.

The deliberate introductions of the species into these locations enabled Laughing Kookaburra to overcome two major distributional barriers that had previously maintained clear geographic demarcation of the various forms: Bass Straight and the Nullarbor Plain. Having once occupied the entire southern regions when “forest birds occurred from east to west” (Keast, 1957, p. 71), they have, since their artificial introduction to these areas, thrived.

However introductions of the Laughing Kookaburra outside of Australian have been less successful. Introduced populations have either failed entirely, or remained small and localised. Attempts at introducing the species into Fiji failed, and plans to liberate it in England were never actioned. The only place it has established a wild population is New Zealand, and that remains limited to an area around North Auckland, from Whangarei to the Waitakere Ranges, as well as Kawau Island and along the western shore of Hauraki Gulf.

This concludes remarks presented in response to the research questions, and attention will now be focussed on the evaluation of the study’s hypothesis. As, based on the findings, it was clearly identified that the focus species, displayed in response to different ecological adaptations, different colonisation strategies.

These in turn, reflected the species individual biology. These adaptations were evident in the various ways each utilised features of the physical and ecological environment of the colonised landscape.

Findings from the research sit well with the main ideas expressed in the theoretical framework, the concepts of biological invasion proposed by Elton (1958), Hengeveld, (1989), and Williamson (1996). It also supports the dynamic approach to the study of biological invasions, as a 'process', rather than an event, proposed by Lockwood *et al.* (2007), through application of the *Invasion Process Model*, which provided a workable framework within which to contextualise the spatial and temporal aspects that are integral to any geographic study.

8.2 Concluding Statements:

This thesis, although limited to the Southwest corner of Australia, is in essence biogeographical. To echo the words of H.R. Mill (1899), when asked as to the purpose of biogeography, it is "to trace out the reasons why particular species occupy the regions where they are now found" (Gentilli, 1979). However, as it has been previously pointed out, it is not a 'stand-alone' discipline, but one that integrates the disciplines of "plant and animal geography and ecology, with many overlaps into genetics, human geography and the social sciences" (Armstrong, 1979).

The activities of humans and their impact on ecosystem function have proved all pervading, to the extent that landuse ecology is recognised as a major component of any biogeographical enquiry. Wildlife management for the 21st century comprises diverse endeavours that extend beyond the management of populations within ecosystems, to encompass tenets of "education, extension, park management, law enforcement, economics, and land evaluation" (Sinclair *et al.*, 2006). Central to contemporary management regimes are core aims that must satisfactorily meet the following outcomes:

- Ensuring the conservation and protection of wildlife and their habitats;
- Protecting people from hazards caused by wildlife;
- Providing opportunities for people to enjoy and learn about wildlife (Miller, 2009, p. 48).

Contemporary wildlife management must address these 'human dimensions' in view of "how people value wildlife, how they want wildlife to be managed, and how they affect or are affected by wildlife and wildlife management decisions" (Decker, Brown, & Siemer, 2001, p. 3). These challenges, have been addressed literally, with strategies evolving that involve "informing people, educating people, seeking people's opinions and regulating people's behaviours (Sinclair *et al.*, 2006, p. 2). These strategies, although developed to address problems at a global scale, have relevance to the present study given the extent to which human behaviours have influenced the colonisation and spread of the focus species.

Numerous committees and groups have been established to assess the ecological and economic impacts of biological invasions (e.g. Scientific Committee on Problems of the Environment; International Union International Union for Conservation of Nature; Invasive Species Council Australia). Each acknowledges that the destruction of natural habitats and disruption of ecosystem function aid the spread of alien species. Already successful colonisers, benefit further "from the reduced competition that follows habitat degradation" (International Union for Conservation of Nature, 2000, p. 3).

Declines in once widespread indigenous species are being reported "with habitat loss, agricultural intensification and reduced rainfall frequently implicated" (Stevens & Watson, 2013). Declining rainfalls have been predicted across southern Australia as a result of climate change, linked to global warming, a phenomenon caused by growing atmospheric levels of CO_2. (Bureau of Meteorology, 2010; CSIRO, 2001; CSIRO & Australian Bureau of Meteorology, 2007; CSIRO & Australian Bureau of Meteorology, 2012). Reduced rainfalls are expected to add to existing environmental problems by further modifying habitat conditions.

A study by Hughes (2003) on the trends, projections and impacts of climate change on Australian ecosystems, and implications for its floristic and faunal species, warns that in general, "species are expected to respond individualistically to future climate change". The consistent message though, is that the distributions of most species will become increasingly fragmented (Hughes, 2003, p. 430).

In Australia, as well as other countries, increased temperatures from anthropogenic climate change have been linked to earlier breeding for some bird species, although there may be other contributory factors (Gibbs, Chambers, & Bennet, 2011, p. 283). Other possible impacts related to changes in climate include declines in "breeding participation, individual reproductive effort, breeding success and breeding density" (2011, p.284).

This suggests that anthropogenic climate change, which influences temperature and rainfall patterns, may have extensive, rapid and ongoing effects on breeding in Australian birds. In particular, the drier conditions predicted for southern Australia are anticipated to have a negative effect on the breeding activity of many species (Gibbs *et al.*, 2011, p. 290).

Another study, (McKechnie, Hockey, & Wolf, 2012) warns that climate change "has profound implications for the conservation and management of arid-zone avifaunas…with potentially catastrophic results for threatened species" (2012, p. iv). The impact of heatwaves on avian mortality has already been experienced in the study area, most recently with the death of 208 Carnaby's Black Cockatoo at Hopetoun (this number is probably a gross underestimate, as chicks in the nest would also have perished but went undetected).

There are, then, anticipated problems confronting conservation and wildlife managers, not just in Australia, but globally, in the coming years. Challenges lie in preserving natural biotas in the face of climate change as well as the spread of alien species.

The consequences of biological invasion have been experienced across continents, but are known to be particularly damaging to island biotas. It has been recognised that islands often support areas of "significant biological diversity" (International Union for Conservation of Nature, 2000, p. 3), including unique and endemic species. Such is the case with the study area, which for the purpose of the present study, has been treated as an island, as it is cut-off by desert or sea along every boundary, and it is a recognised global 'biodiversity (Brooks et al., 2007; Department of Sustainability, 2009; Mittermeier et al., 2004; Myers et al., 2000).

The goal, for all stakeholders therefore must aim "to prevent further losses of biological diversity due to the deleterious effects of alien invasive species" (International Union for Conservation of Nature, 2000, p. 4). Working toward this outcome requires a multi-faceted approach: to improve understanding, strengthen response, provide legal and institutional support and increase knowledge through research efforts. In response to such need, the IUCN developed a strategy toward attaining these outcomes. They are listed as:

- To increase awareness of alien invasive species as a major issue affecting native biodiversity in developed and developing countries and in all regions of the world;
- To encourage prevention of alien invasive species introductions as a priority issue requiring national and international organisation;
- To minimise the number of unintentional introductions and to prevent unauthorised introductions of alien species;
- The ensure that intentional introductions, including those for biological control purposes, are properly evaluated in advance, with full regard to potential impacts on biodiversity;
- To encourage the development and implementation of eradication and control campaigns and programmes for alien invasive species, and to increase the effectiveness of those campaigns and programmes;
- To encourage the development of a comprehensive framework for national legislation and international cooperation to regulate the introduction of alien species as well as the eradication and control of alien invasive species;
- To encourage necessary research and the development of sharing of an adequate knowledge base to address the problem of alien invasive species worldwide (International Union for Conservation of Nature, 2000, p. 5).

Within Australia, seeking to rectify problems arising from the human dimension upon wildlife management is not new. The work of Jones, Enck, Siemer, Decker and Brown (1998) found that many wildlife managers encountered 'people problems' within the scope of their directives. The problems arose, they said, because the expertise of managers was primarily biological and technical, and they directed "little or no attention to 'social issues" (1998, p. iii). Although there has since been attempts to rectify this, such efforts "remain exceptions rather than 'the rule" (Miller, 2009, p. 51) due to an enduring 'biological bias' in wildlife management.

There is a strong case for further research linking conservation science to socio-political factors to foster community understanding of the impacts of invasive species. To aid the success of future projects, which have in the past been criticised as "reactive and patchy in their geographical and species coverage" (2009, p. 52), they need to extend to include the human dimensions paradigm. Although it will demand "patience, empathy and tolerance, and a willingness to be involved with many different kinds of people" (Gilbert & Dodds, 1992, p. 49), the future well-being of our wildlife resources depends on it.

The presence of the focus species within the study area is widely accepted. They have become so intergral to the landscape, there is a strong community perception that they are indigenous to the Southwest region, their exotic origins have been lost in time. Future management may only ever be successful if upcoming generations once again, come to regard them as invaders.

The present study has shown that their presence, albeit seemingly innocuous, has the potential to become problematic, for example, in terms of community and livestock health, in relation to the carriage of pathogens and parasites harboured by the Australian White Ibis and the *Streptopelia* doves. Problems may also develop for some 'at risk' native species, through the decimation of their populations as a food source, or as a result of increased ecological competition, as described in relation to the Laughing Kookaburra.

Other than these perceptible biological and ecological problems, there is another aspect to consider, that of the 'cultural aesthetic'. □□□ □□□□□□□□□□□□□□□□ □□□□□□□□□□□□□d□□□□d □□"the physical configuration of our surroundings but in the haptic layer of sounds, smells, and substances that fill our ears and lungs and are absorbed deep into our bodies" (Berleant, 1991, p. 77). In *Sense of Place*, George Seddon sought to encapsulate these intangible aspects in his exploration of the physical geography of the Swan Coastal Plain, by presenting readers with examples of its ancient forms and rare species. Within decades of the arrival of Europeans, and the plethora of exotic plants, animals, and birds they bought with them, the once isolated and unique environment of the Southwest was altered irrevocably, forever. Even the immigration of the White Ibis into the study area was aided by European farming practices.

By the time Seddon wrote: "The first step in design is recognition, the ability to see what there is" (Seddon, 1972), it was too late to preserve the entire biodiversity of the region, and its many unique and endemic species, and to stem the tide of invaders from within.

8.3 Guiding Principles:

The management of invasive species to prevent and limit ecological, environmental and economic damage is becoming increasingly necessary. As problems with invasive species are not limited to exotic species, with a few indigenous Australian generalist species also becoming increasingly abundant and raising concerns e.g. Australian White Ibis, Australian Raven.

The development of strategies toward this end have progressed over the last few decades, with the 'Convention of Biological Diversity' opened for signature at the *Earth Summit* in Rio de Janeiro in 1992 (and 'entered into force' in 1993). The principle of the convention "advocates a hierarchical intervention approach for new, emerging and widespread invasive species (Secretariat of the Convention in De Milliano et al., 2010).

This approach has been woven into major national invasive species management plans, such as the *Australian Pest Animal Strategy* and the *Australian Weed Strategy* (Natural Resource Management Ministerial Council, 2007a, 2007b). It is also integral to the management approach of invasive species in Western Australia, and features in the monitoring framework for invasive species developed by DAFWA (De Milliano et al., 2010). The four strategies for the management of invasive species proposed are: Prevention, Eradication, Containment and Management. Each have aims and outcomes specific to them, and relate to four invasion stages (as identified by Emerton & Howard, 2008). These have been adapted to correspond with the stages set-out in the *Invasion Process Model* (Lockwood *et al.*, 2007), to reflect the chronology of the present study (Table 8.1).

Table 8.1: Management strategies for Invasive Species
(As per Emerton & Howard, 2008)
(Adapted to include Invasion Process Model as per Lockwood *et al.*, 2007)

Management Strategies for Invasive Species				
Stage of Invasion	**Management Strategy**	**Aim of the Strategy**	**Intermediate Outcomes**	**As per Lockwood (2007)**
Stage 1: Introduction: The species is absent	1. Prevention	Stopping introductions	No new high risk invasive species are introduced	Transport
Stage 2: Colonisation/ Establishment: The species has established a founding population(s)	2. Eradication	Eradicating a new population	Identified high risk invasive species are eradicated	Era A:
Stage 3: Naturalisation: The species is starting to spread and establish multiple populations	3. Containment	Stopping a new population from spreading	Priority established invasive species are contained	Era B:
Stage 4: Invasion: The species has demonstrated its invasive capacity and is impacting on assets	4. Management	Protecting assets	The negative impacts of invasive species on priority assets are minimised; habitat and agricultural productivity are protected; amenity appreciation is enhanced	Era C

Brief explanations of the strategies are given below. Examples of bird species being managed according to the stratagem in Western Australia are given.

Prevention (Stage 1): Considered the most cost effective and environmentally desirable. The aim is to stop the introduction (Stage 1) of new high risk invasive species. Although complete prevention is unlikely and risk management will be required to identify and assess risks and feasibility of managing species after introduction to determine management priorities. Tools include monitoring and surveillance to confirm absence; risk and pathway analysis; education and awareness, listing of high risk species and border controls e.g. in Western Australia, Fischer's Lovebird (*Agapornis fischeri*); Red-lored Amazon (*Amazona autumnalis*);

- **Eradication** (Stage 2): Involves removing newly arrived or emerging invasive species from the wild. This phase requires surveillance and monitoring to ensure early detection in conjunction with efficient reporting and rapid response to reporting. Fundamentally this management strategy is rapid response and on-ground action to ensure eradication of population(s) e.g. in Western Australia, Indian Ringneck Parakeet (*Psittacula Krameri*);
- **Containment** (Stage 3): Preventing the spread of established species to new areas (species at Stage 3 of the invasion process). Approach maintained by containing distribution and/or limiting the density of the invasive species. Requires monitoring to focus how the containment strategy impacts on the distribution and abundance of the species: to track management investment and actions e.g. in Western Australia, Sulphur-crested Cockatoo (*Cacatua galerita*);
- **Management** (Stage 4)**:** Aims to minimise overall adverse impacts of abundant and widespread invasive species throughout their potential range rather than managing the population in itself. Asset based approaches are the most common to deal with invasive species at this phase. It is The stratagem is "sensitive to the scale of management" (De Milliano et al., 2010, p. 8) e.g. in Western Australia, Rainbow Lorikeet (*Trichoglossus haematodus*).

The birds listed for Stages 2-4, are species that have been permitted into Western Australia for use in aviculture. They were initially considered for inclusion in the present study and were profiled briefly at the start (refer Page 1).

As previously stated, the Indian Ringneck is a high priority 'Eradication' target, with all reported sightings assigned a 'rapid response team' to recapture specimens. (DAFWA, 2007).

Whereas, the Sulphur-crested Cockatoo, which presents a threat of much lower magnitude and is already established in parts of the Southwest, is subject to 'Containment' objectives whereby feral populations are reduced whenever possible to limit populations and prevent crop damage (DAFWA, 2001). The strategy also limits impacts on local species such as the Western Long-billed Corella (*Cacatua pastinator*) and Short-billed Corella (*C. sanguinea*), as well as endangered Baudin's Cockatoo, Carnaby's Cockatoo and forest Red-tailed Black Cockatoo, which are already facing problems arising from habitat loss and degradation.

For Rainbow Lorikeet however, objectives relate solely to 'Management', as the pre-emptive strategies of eradication or containment were not implemented, or initiated too late, with little or no action taken to eradicate them when they were first recorded in Perth in the 1960s. From these few, the population has grown to extend across much of the metropolitan area and was expected to exceed 20,000 birds by 2010 (Chapman and Massam, 2007).

The population now threatens a range of crops, exerts ecological competition pressure on native species for nest sites and food; and poses a potential disease risk to wild and captive parrots as carriers of psittacine beak and feather disease. Community aesthetics are also diminished due to their fouling areas and making noisy passage in flocks of 10-50 birds. A large population near Perth Airport also poses an aircraft-strike risk. The species now presents an "extreme risk to the social, environmental and agricultural values of the state (Chapman, 2005).

Other than these aviculture species, successful global colonisers, such as Common Starling, House Sparrow and Tree Sparrow, have also been subject to 'Prevention' and 'Eradication' strategies. The absence of (or isolated, limited populations) of these aggressive colonisers in Western Australia, lets the results speak for themselves. The hyper-vigilance of authorities is supported by legislation and is funded to keep teams active in controlling these species. The environmental and economic benefits of maintaining this vigilance have been proven to outweigh the costs, and reflect the adage, that 'prevention is better than a cure'.

It has been well documented that some species of birds "cause problems that necessitate preventive action" (Feare, 1990, p. 463), including agricultural and horticultural damage, fouling of buildings and infrastructure, health hazards from contact with pathogens, predation of indigenous species and competition for resources. As a consequence there are instances were some "have been killed as attempts to resolve all these problems (1990, p.463). The focus of such campaigns, on killing as many as possible, with little attention given to gauging the extent to which doing so has resolved problems.

Hindsight has evidenced that often culling is ineffective as well as being "environmentally dangerous, unselective, and expensive" (1990, p.463) . It should only be considered when all other options have been investigated, and failed. Damage prevention strategies should first consider "the simplest, cheapest, and environmentally safest options" (1990, p.474) with culling an absolute "last resort" option. That is certainly the view held here. What is sought is not the destruction of populations, but the revision of bad practices: to educate people to interact in a meaningful way with nature, in ways that promote positive exchanges.

Although many Australians still identify with the 'bushman' persona that developed from our nation's early rural settlement history, most live in coastal urban areas. An outstanding feature of these areas is the "retention of indigenous and other flora in parks, amenity plantings, and private gardens… sufficient habitat to support a wide range of wildlife species" (Temby, 2004, p.26).

However, as human population densities increase, block sizes diminish, and areas of remnant bushland disappear, people seek to experience nature within the confines of their own garden and locality. For many, the provision of food, water and other resources allows them to engage with, feed and sometimes handle, some birds and mammals (Temby, 2004), which denotes a feeling of 'connectedness' to nature.

Unfortunately not all interactions are invited or enjoyable and situations have developed where human interests and urban wildlife conflict (Temby, 2004) and the resultant polarised view within urban communities becomes about 'problem species'. The best practice management of these scenarios requires the implementation of plans that limit the negative impacts of wildlife upon urban communities, and of urbanisation upon wildlife.

Strategies that adopt sustainable and practical approaches (Temby, 2004), such as reducing unnatural food sources, limiting nesting opportunities and educating the public, constitute best practice. This study has attempted to highlight how the actions people, in their interactions with wildlife, promote the spread of these exotic and potentially invasive species: with planning and design, the process could be reversed.

It is understood that suburban development has had "a major effect on biodiversity as a result of the magnitude, intensity and permanence of the changes wrought" (Crates *et al.*, 2011). Within the coastal regions of Australia, avian communities are still adapting to changes resulting from the growth of suburbs. Issues around biodiversity conservation are still being recognised.

The birds included in this study have been identified as 'generalist' species, with non-specific dietary requirements. They are able to access and consume a wide range of food sources. Other than these feeding advantages over 'specialist' species, they have adapted their breeding habits to the urban environment and will nest in artificial structures. These aspects have afforded them ecological advantages not suited to specialist native species. It has been clearly identified that specialist species are suffering as result of the "homogeneous collection of 'urban exploiters' (Marzluff et al., 2001; Turner et al., 2004), that are increasingly present in urban areas, such as the focus species.

Therefore, conservation efforts, rather than just taking a 'control' approach to non-natives; should also focus efforts that benefit disturbance sensitive species. It is essential conservation efforts are able to diversify in order to "encourage disturbance-sensitive species or limit urban exploiters" (Crates *et al.*, 2011, p. 341). There are those that, whilst not advocating the abandoning of efforts at mitigating serious problems caused by introduced species, or stopping potentially harmful species from entering, believe it time for a paradigm shift in conservation management. A shift toward organising priorities "around whether species are producing benefits or harm to biodiversity, human health and ecological services and economies" (Davies *et al.*, 2011, p. 154), that focuses "much more on the functions of species, and much less on where they originated".

However, whilst the time may be upon us to broaden approaches to conservation management, what is vital, is that in so doing, the tactic convictions of the sceptical philosopher are not allowed to dominate. Arguments that ecosystems have long experienced damage throughout evolutionary history, and that "the current human-induced destruction is within the range of evolutionary precedents" (Tokeshi, 1999, p. 361); along with beliefs that ecosystems the world over are not so badly damaged they require changes in ongoing practices to protect them; and that despite the current and exceptional scale of human induced destruction wrought on the planet, that nature will take care of the future "whatever the ultimate fate of humans may be" (1999, p. 361); places little value on people, or nature.

8.4 Directions for Future Research:

Arising from the findings of the present study, several initiatives for further research have been identified.

Foremost amongst them is research focussed on the Laughing Kookaburra in relation to the ecological impact of the species in the Southwest, by way of addressing the existing knowledge gap. Research efforts may be best served concentrating on areas set aside under the *Conservation and Land Management Act* 1984 (CALM Act), including national parks, conservation parks, nature reserves, State forest and timber reserves with an aim to identifying:

- Interspecific interactions with indigenous birds and mammal species with a focus on 'at risk' species;
- Types of prey taken and extent of prey taking;
- Extent of nest predation;
- Nest site preferences;
- Main food types of nesting Kookaburras.

A further direction for research lies in extending the spatial and temporal limits of the present study to a quantitative study of population densities of the focus species (as per the present author, Moon, 2005):

- To investigate the impact of exotic aviculture species with established populations in the study area utilising the methodology developed for the present study.

Other than ideas for future research, a number of initiatives were identified to be encouraged of key stakeholders, including State and Local Government entities:

- Wetland recovery projects aimed at restoring and enhancing natural habitats in sites affected by salinity and/or eutrophication and/or habitat degradation to develop them as all-purpose sites for water-bird populations;

- Verge re-vegetation, planting of trees and shrubs to increase extent of native vegetation coverage in urban areas, to diminish weed growth, form wildlife corridors between remnant habitats, and deter foraging by generalist species;

- Increased signage in wetlands, parklands, and public areas discouraging hand-feeding of native and non-native bird species;

- A coordinated response to bird management at refuse sites to avert foraging birds to alternate sites e.g. use of scaring tactics such as predator calls and expedient coverage of waste;

- A coordinated response to bird management at outdoor restaurants, cafés, entertainment complexes to divert foraging birds to alternative sites e.g. being moved on by staff, efficient removal of left-over foods, covered rubbish bins, signage to discourage feeding of wild birds by patrons.

In closing, it can be clearly stated that the justifications put forward in support of the research have been proven to be well-founded, as it is believed that the present study has succeeded in augmenting existing knowledge of avian invasion events in the Southwestern Australia, it has attempted to identify factors that enhanced and inhibited the colonisation success of the focus species within the study area, and to describe problems resulting from their arrival. It has also made suggestions as to directions in future research designed to safeguard regional biodiversity.

It is also ascertained that the stated aims of the research were met i.e. a comprehensive dataset of historical data suited to GIS analysis was constructed, spatial and temporal patterns of dispersal of the focus species within the study area subsequent to colonisation were identified, associations between the ecology of the focus species and these patterns were investigated, and the species distributions were examined in relation to geographic and anthropogenic features of the study area.

In meeting these aims, the research questions proposed to investigate the hypothesis were addressed (refer page 9).

The responses arrived at and detailed were drawn from results produced within the methodological framework developed in the study design.

The completed investigation of which, enabled the hypothesis to be established as valid.

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APPENDICES

Appendix 1: Data Request Letter

Desireé L Moon

15 Trott Road

LESMURDIE WA 6076

30 July 2007

Name

Address 1

Address 2

Dear

I am currently undertaking doctoral research at Edith Cowan University. My research project is titled *The Dispersal of Introduced Avian Species in Southwestern Australia*. Following an initial enquiry to personnel at Birds Australia (WA), I was directed to you as a possible source of historical RAOU sightings data.

The study area is delimited by the coastal shoreline, and a line extending from Geraldton (28° 45'Lat / 114° 35' Long), passing through Merredin, (31° 29' Lat / 118° 17' Long) and terminating in Esperance (33° 50'Lat / 121° 50' Long). The focus species identified for the study include:

- Australian White Ibis (*Threskiornis molucca*)
- Laughing Kookaburra (*Dacelo novaeguineae*)
- Rainbow Lorikeet (*Trichoglossus haematodus*)
- Sulphur-crested Cockatoo (*Cacatua galerita*)
- Spotted Turtle-dove (*Streptopelia chinensis*)
- Laughing Turtle-dove (*Streptopelia senegalensis*)

If you are able to provide access to these records, could you please contact me by phone 9291 9265, mobile 0413 929 367 or email dlmoon@student.ecu.edu.au.

I understand that you have many demands on your time and appreciate you taking the time to consider my request. All data provided will be limited to use in the thesis and will not be used in any other publications without prior permission.

Regards,

DESIREÉ L MOON

Appendix 2: Birds Australia - Application for Data
(Exception to copyright: Section ss 40, 103C for Research or Study)

APPLICATION FOR DATA

COMPANY: _____

CONTACT PERSON: ----------

POSTAL ADDRESS: ----------

_____

_____

PHONE NO: ( ) _____ FAX NO: ( ) _____

EMAIL:

_____

PROPOSED USE OF DATA:

Applicant or Authorised Officer: _____ Date _____/_____/20_____

CONDITIONS

In purchasing data from the Royal Australasian Ornithologists Union (A.B.N. 87 004 076 475) of 415 Riversdale Road, Vic., 3123 ("the RAOU"), the Purchaser agrees to be bound by all of the following conditions.

1. In these conditions, "data" means information collected and analysed by the RAOU.

2. The Purchaser agrees to pay the RAOU the amount of any licence fee(s) charged by the RAOU for the use of the data in accordance with the terms of the RAOU for payment. If payment is not made in accordance with those terms, the RAOU may cancel this agreement without prejudice to any rights it has under this agreement or at law, including the right to recover licence fees.

3. The Purchaser will not, without first obtaining the consent of the RAOU, use any data supplied by the RAOU other than for the use proposed by it in its application. If there is any such variation in the use of the data, the RAOU may in that event charge such further licence fees as it decides.

4. The Purchaser accepts that all Intellectual Property rights connected with the data shall always remain the property of the RAOU.

5. The Purchaser will give proper acknowledgment to the RAOU as being the source of the data in all publications in which the Purchaser makes use of the data.

6. The Purchaser will ensure that it uses appropriate security measures to ensure that the data are not subject to unauthorised use or theft.

7. The RAOU makes no representation whatsoever about the correctness of the data or the use to which they may be put and the Purchaser agrees that it has not made this application in reliance upon any such representation.

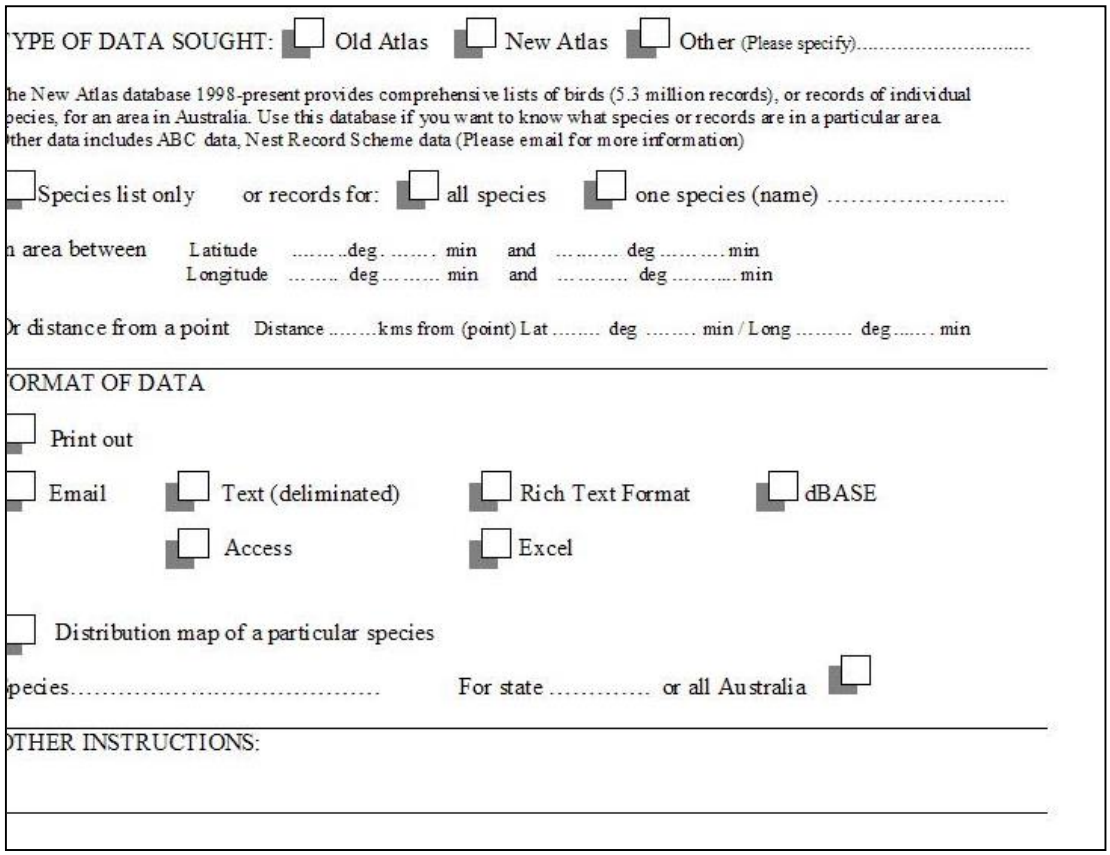
8. Any rights granted to the Purchaser to use the data will be personal to it and will not be able to be assigned to any third party without the consent of the RAOU first being obtained.

9. If the Purchaser fails to comply with any of these conditions, its right to continue to use the data will be withdrawn.

10. This document will constitute the whole of the agreement reached between the parties and shall be governed by the laws of the State of Victoria, Australia.

11. This data application is not part of any previous data agreement between the RAOU and the Purchaser. It does not prejudice any future negotiations with any State Department regarding data exchange/subscription.

DATA REQUEST INFORMATION



YPE OF DATA SOUGHT: ☐ Old Atlas ☐ New Atlas ☐ Other (Please specify).....

he New Atlas database 1998-present provides comprehensive lists of birds (5.3 million records), or records of individual pecies, for an area in Australia. Use this database if you want to know what species or records are in a particular area. ther data includes ABC data, Nest Record Scheme data (Please email for more information)

☐ Species list only or records for: ☐ all species ☐ one species (name) .....

n area between Latitude .....deg..... min and ..... deg ..... min
Longitude ..... deg..... min and ..... deg ..... min

r distance from a point Distance .....kms from (point) Lat ..... deg ..... min / Long ..... deg..... min

ORMAT OF DATA

☐ Print out

☐ Email ☐ Text (deliminated) ☐ Rich Text Format ☐ dBASE

☐ Access ☐ Excel

☐ Distribution map of a particular species

pecies..... For state ..... or all Australia ☐

THER INSTRUCTIONS:

Appendix 3: ABBBS Agreement for Supply of Data form
(Exception to copyright: Section ss 40, 103C for Research or Study)

Australian Government
Department of the Environment, Water, Heritage and the Arts

Agreement for the Supply of Data

Important: The completed Schedule and Licence Conditions set out below will constitute a legal agreement between the Commonwealth of Australia ("the Commonwealth") and you ("the Licensee") in relation to the data. If you agree with the Conditions, please sign below and return a copy to the Commonwealth contact.

If you are entering into this agreement on behalf of a company or organisation, you warrant that you have the authority to do so.

SIGNED: DATE:

The Schedule

Date: 28 February 2008

Commonwealth

The Commonwealth of Australia is represented by the Department of the Environment, Water, Heritage and the Arts. The contact details are:

Name/Title:	Mr David Drynan, Senior Project Officer, Australian Bird & Bat Banding Scheme Department of the Environment, Water, Heritage & the Arts
Address:	GPO Box 8 Canberra ACT 2601
Telephone:	02-62742407
Facsimile:	02-62742455
Email Address:	david.drynan@environment.gov.au

Licensee

Name/Title:	Ms Desiree Moon
Address:	15 Trott Road LESMURDIE WA 6076
Telephone:	08-92919265
Email Address:	dbcmoon@iinet.net.au

Appendix 4: MS Access – Bird Data Compilation sample

Era	ID	COMMON NAME	SCIENTIFIC NAME	DATE SIGHTE	YEAR	LOCATION	DEC LAT	DEC LONG	BREEDING	SOURCE	Latitude_Deg	Longitude_Deg
A	78244	Spotted Turtle-dove	Streptopelia chinensis		1898		-30.0833333	115.9166667	1	RAOU	-30.083333333	115.9166666667
A	78165	Laughing Turtle-dove	Streptopelia senegalen		1898		-31.9166667	115.5833333	1	RAOU	-31.916666667	115.5833333333
A	78266	Laughing Kookaburra	Dacelo novaeguineae		1898		-31.9166667	115.9166667	1	RAOU	-31.916666667	115.9166666667
A	77705	Spotted Turtle-dove	Streptopelia chinensis		1898	Perth	-31.95301	115.85717	0	SJDB	-31.95301	115.85717
A	78312	Laughing Kookaburra	Dacelo novaeguineae		1898		-30.083333	115.916667		RAOU	-30.083333	115.916667
A	77706	Spotted Turtle-dove	Streptopelia chinensis		1899	Perth	-31.95301	115.85717	0	SJDB	-31.95301	115.85717
A	77707	Spotted Turtle-dove	Streptopelia chinensis		1900	Perth	-31.95301	115.85717	0	SJDB	-31.95301	115.85717
A	62128	Laughing Kookaburra	Dacelo novaeguineae		1902	Mundaring Weir			0	SJDB	-31.95772	116.16357
A	62129	Laughing Kookaburra	Dacelo novaeguineae		1903	Gingin			0	SJDB	-31.34606	115.91077
A	62130	Laughing Kookaburra	Dacelo novaeguineae		1904	Guildford			0	SJDB	-31.90052	115.96718
A	70835	Laughing Turtle-Dov	Streptopelia senegalen	5/05/1905	1905	Clackline	-31.718	116.521	0	SJDB	-31.71885	116.51969
A	70834	Laughing Turtle-Dov	Streptopelia senegalen	5/05/1905	1905	Goomalling	-31.3	116.831	0	SJDB	-31.3011	116.82965
A	70833	Laughing Turtle-Dov	Streptopelia senegalen	5/05/1905	1905	Konnongorring	-31.052	116.776	0	SJDB	-31.05277	116.77439
A	70832	Laughing Turtle-Dov	Streptopelia senegalen	5/05/1905	1905	Cunderdin	-31.656	117.233	0	SJDB	-31.65718	117.23189
A	70831	Laughing Turtle-Dov	Streptopelia senegalen	5/05/1905	1905	Wooroloo	-31.803	116.314	0	SJDB	-31.8044	116.31301
A	70830	Laughing Turtle-Dov	Streptopelia senegalen	5/05/1905	1905	Merredin	-31.483	118.286	0	SJDB	-31.48415	118.28415
A	70829	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Wooroloo	-31.803	116.314	0	SJDB	-31.8044	116.31301
A	70827	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Jandakot	-32.107	115.867	0	SJDB	-32.10803	115.86575
A	70836	Laughing Turtle-Dov	Streptopelia senegalen	6/05/1905	1905	Bickley Brook Re	-32.03	116.036	0	SJDB	-32.03	116.036
A	70840	Laughing Turtle-Dov	Streptopelia senegalen	8/05/1905	1905	Bunbury	-33.34	115.642	0	SJDB	-33.34135	115.64051
A	70826	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Hopelands	-32.375	115.909	0	SJDB	-32.37635	115.908
A	70825	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Mandurah	-32.529	115.723	0	SJDB	-32.5305	115.7219
A	70824	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Harvey Estuary	-32.7	115.678	0	SJDB	-32.70136	115.67689
A	70823	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Harvey	-33.078	115.894	0	SJDB	-33.07885	115.89299
A	70822	Laughing Turtle-Dov	Streptopelia senegalen	3/05/1905	1905	Northam	-31.653	116.666	0	SJDB	-31.64799	116.66747
A	70828	Laughing Turtle-Dov	Streptopelia senegalen	4/05/1905	1905	Kellerberrin	-31.63298	117.70634	0	SJDB	-31.63298	117.70634
A	70844	Laughing Turtle-Dov	Streptopelia senegalen	9/05/1905	1905	Seabrook	-31.664	116.736	0	SJDB	-31.66549	116.73497
A	70852	Laughing Turtle-Dov	Streptopelia senegalen	17/05/1905	1905	Harvey	-33.078	115.894	0	SJDB	-33.07885	115.89299
A	70851	Laughing Turtle-Dov	Streptopelia senegalen	16/05/1905	1905	Collie	-33.357	116.15	0	SJDB	-33.35497	116.15082
A	70850	Laughing Turtle-Dov	Streptopelia senegalen	16/05/1905	1905	Harvey	-33.078	115.894	0	SJDB	-33.07885	115.89299
A	70849	Laughing Turtle-Dov	Streptopelia senegalen	15/05/1905	1905	Harvey	-33.078	115.894	0	SJDB	-33.07885	115.89299
A	70848	Laughing Turtle-Dov	Streptopelia senegalen	13/05/1905	1905	Northam	-31.653	116.666	0	SJDB	-31.64799	116.66747
A	70847	Laughing Turtle-Dov	Streptopelia senegalen	12/05/1905	1905	Bibra Lake	-32.099	115.818	0	SJDB	-32.09635	115.82356
A	70838	Laughing Turtle-Dov	Streptopelia senegalen	6/05/1905	1905	Meckering	-31.603	116.991	0	SJDB	-31.63049	117.01025
A	70845	Laughing Turtle-Dov	Streptopelia senegalen	10/05/1905	1905	Katanning	-33.692	117.583	0	SJDB	-33.69217	117.5533
A	70837	Laughing Turtle-Dov	Streptopelia senegalen	6/05/1905	1905	Corrigin	-32.327	117.875	0	SJDB	-32.32829	117.87328
A	70843	Laughing Turtle-Dov	Streptopelia senegalen	9/05/1905	1905	Bunbury	-33.34	115.642	0	SJDB	-33.34135	115.64051
A	70842	Laughing Turtle-Dov	Streptopelia senegalen	8/05/1905	1905	Williams	-33.025	116.881	0	SJDB	-33.02581	116.87993
A	70841	Laughing Turtle-Dov	Streptopelia senegalen	8/05/1905	1905	Corrigin	-32.327	117.875	0	SJDB	-32.32829	117.87328
A	70818	Laughing Turtle-Dov	Streptopelia senegalen	2/05/1905	1905	Quairading	-32.01	117.399	0	SJDB	-32.01136	117.398
A	70839	Laughing Turtle-Dov	Streptopelia senegalen	7/05/1905	1905	Dangin	-32.04	117.331	0	SJDB	-32.04137	117.32912
A	70821	Laughing Turtle-Dov	Streptopelia senegalen	3/05/1905	1905	Wyalkatchem	-31.177	117.383	0	SJDB	-31.17857	117.38189
A	70846	Laughing Turtle-Dov	Streptopelia senegalen	10/05/1905	1905	Kellerberrin	-31.63298	117.70634	0	SJDB	-31.63298	117.70634

Appendix 5: Community Attitudes Survey

INVASIVE AVIAN SPECIES IN SOUTHWESTERN AUSTRALIA

INFORMATION & CONSENT FORM

(http://members.iinet.net.au/~mastech/moon/consent.html)

(dlmoon@our.ecu.edu.au)

Patterns and Processes of Dispersal: A Biogeographical Study of Invasive Avian Species in Southwestern Australia

My name is Desiree Moon. I am a student at Edith Cowan University, Mt Lawley Campus. I am working toward a Doctor of Philosophy in Cultural and Community Studies. My Academic Supervisor is Dr. Hugo Bekle. I have full ethics approval from the Education and Arts Higher Degrees Office for my research.

The study is designed to identify and investigate the dispersal of invasive birds throughout Southwestern Australia. Central to the research is how the feeding and breeding ecology of the target species has influenced dispersal following its arrival or introduction into the study area.

The terms of participation are voluntary and participants are not obliged to complete the survey. Anonymity is assured, as the survey does not request or require any personal details. Information is confidential and all documents and records will be stored on a personal computer or disk in a locked office at my residence or alternately, on a disk or as hard copy in a locked cabinet and storeroom at the University (room 17.124).

If you have queries regarding the study or your participation in the survey please do not hesitate to contact any one of the following persons:

Desireé Moon
Researcher
Phone: 0413 929 367; or

Dr Hugo Bekle
Supervisor
Phone: 9370 6148

Survey Questions

(http://members.iinet.net.au/~mastech/moon/questions.html)

- Have any of the target species ever been present in your garden or surrounds? If so, what is your suburb? Can you recall when they have been present? (month and/or year)
- Have you seen the target species at any other locations throughout Southwest of WA? If so, where? Can you recall when they have been present? (month and/or year)
- Do the target species make use of food/water/vegetation in your garden or surrounds? If so, how?
- Have you seen evidence of nesting or breeding by the any of the target species in your suburb or other areas with Southwest WA? What trees/shrubs or other places have nests been constructed in?
- Do you have any other comments to add in regards to the target species or the research project?

Appendix 6: Local Government refuse site enquiry

Desireé L Moon
15 Trott Road
LESMURDIE WA 6076
Ph: 08 9291 9265
Mob 0413 929 367
Email dbcmoon@iinet.net.au
Email 2: dlmoon@student.ecu.edu.au

4 September 2009

Manager
Waste Management Services

Dear Sir/Madam,

I am currently conducting PhD research at Edith Cowan University on the dispersal of introduced avian species throughout the Southwest of Western Australia. One of the target species I am researching is the Australian White Ibis (*Threskiornis molucca*), which prior to 1952, was restricted to the Kimberley Region in the State's far north. If you are not familiar with the species, I have included a picture to identify them.

However, since its arrival at around this time it has become widespread and prolific throughout the Perth metropolitan area and beyond. They are adept scavengers and often utilise refuse sites to obtain food.

I am interested in knowing if they are a problem at any of the rubbish tips in your local government area? If so, are they subject to a specific management plan to reduce their number?

Thank you for considering my request.

Regards,

Desireé L Moon

Appendix 7: Food types of *Streptopelia* doves
(Extent and availability in Study Area) (Part 1)

Notes on Native and Naturalised Foods of *Streptopelia* Doves in Study Area			
Type	**Species**	**Location/Description**	**Habitat**
Crocosmia	*Crocosmia* x *crocosmiiflora* (Montbretia)	Type present in southwest WA is sterile hybrid of two South African species. Popular garden plant that flowers in summer	Road verges and wastelands
Ranunculus (Buttercups)	*R. muricatus; R. trilobus* (naturalised)	There are five native to WA, common in undisturbed bushland. Two introduced species. Extends from Swan Coastal Plain to Albany. Native to Mediterranean. Summer flowering. Suits many soil and climate conditions	Lawns and domestic gardens; disturbed wetlands and winter-wet places
Gladiolus		Are native to Africa and the Mediterranean. Eight species introduced as garden plants into WA have become naturalised	Domestic Gardens
	G.angustus (Long-tubed Painted Lady)	Swan River estuary. Extends to Albany. Spring flowering	Road verges, wasteland and bushland
	G. caryophyllaceus (Pink Gladiolus)	Common on the Swan Coastal Plain. Extends inland to Lake Grace. Spring flowering	Urban bushland and banksia woodlands
	G. undulatus (Wavy Gladiolus)	Grows in the wetter areas of the southwest from the SCP to Albany. Flowers in early summer. Forms up to 30 small corms a year	Road verges, creek banks, wetlands and estuarine sites . Invades bushland adjacent to disturbed sites.
	G. cardinalis	Established in Busselton	
	G. carneus	Found around old settlements between Busselton and Albany	Road verges
	G. tristis	Common between Wagin and Busselton	Disturbed winter-moist sites
	G. communis	Near old settlements between Busselton and Augusta. Unlike all other naturalised species that are from South Africa, it is native to the Mediterranean. All gladiolus also spread from seed	Road verges
Avena	*A. sativa*	A common variety of oat encountered on country road and rail verges as a result of seed dropped during transport. Invasive if not controlled. More common in WA in uncropped situations is *A. barbata* (bearded oat) often present on road verges, in wasteland and disturbed bushland. Native to Mediterranean and Asia	Road and rail verges
	A. barbata (Bearded Oat)	More common in WA in uncropped situations. Native to Mediterranean and Asia	Road verges, wasteland and disturbed bushland
Cynodon sp.	*C. dactylon* (Couch Grass)	Flowers in late spring and summer. Widely planted lawn grass. Introduced to Southwest WA. Native of Kimberley region and tropics worldwide	Invades road verges, wetlands and river edges
Eleusine sp.	*E. coracana*	Only species in Perth which has been collected from sites around Perth but is classified as 'doubtfully naturalised'. It may be more widespread than WA Herbarium indicates	
Hordeum sp.		Barley grasses. All spring flowering	
	H. geniculatrum (Mediteranean Barley Grass)	Common from Perth to Busselton. Native to Mediterranean and Southwest Asia	Disturbed sites
	H. glaucum Northern Barley Grass):	Widespread. Extends inland in the north to Perth	Disturbed sites, grazed woodlands and shrublands
	H. leporinum (Barley Grass)	Widespread throughout southwest WA. Native to the Mediterranean	Crops, pastures, offshore islands, road verges and disturbed sites
	H. marnum (Sea Barley)	Extends from Wongan Hills in the northeast, to the Stirling Range in the south. Native to southern and western Europe	Disturbed or grazed, often saline sites
	H. vulgare (Barley)	Is an important grain crop. Native to Europe	Occurs as a weed wherever seed is spilt on roads, rail verges. It does not persist

Food types of *Streptopelia* doves
(Extent and availability in Study Area) (Part 2)

Type	Species	Location/Description	Habitat
Poa sp.		There are seven native and four introduced species in WA.	
	P. annua (Winter Grass)	Flowers mainly in winter to spring, but now and then throughout year. Extends north, east and south. Native to Europe	Common garden weed and scattered weed of disturbed areas. Increasing crop and pasture weed in southern agricultural region
	P. bulbosa (Bulbous Meadowgrass)	Flowers in spring and summer. Native to western Europe and the Mediterranean	Wastelands and road verges in the Pemberton area
	P. infirma (Early Wintergrass)	Similar to *P. annua* but smaller and finer. Flowers in winter. Native to Europe	Common garden weed and scattered weed of disturbed areas. Increasing crop and pasture weed in southern agricultural region
	P. pratensis (Kentucky Blue Grass)	Flowers in spring and summer. Planted as lawn grass. Sparingly naturalised in areas along Avon and Helena rivers. Native of Europe and temperate Asia	Lawns and river sides.
	Triticum aestivum (Wheat)	Flowers in spring and summer. An important crop plant. Probably not naturalised. It is a hybrid species originating in the Mediterranean and western Asia	Occurs on road verges throughout the southwest, growing from spilt grain.
	Zaluzianskya divaricata (Zedweed or Spreading Night Phlox	Flowers in spring. Widespread throughout southwest. Native to South Africa	Abundant on road verges in paddocks and disturbed woodlands
Rumex spp.	*R. acetosella* (Sorrel, Sheep's Sorrel)	Extends from Moora to Esperance. Native of Europe and Asia	Weed in pastures, on road verges, disturbed wetlands, woodlands, creeks and granite slopes
	R.brownii Swamp Dock)	Perth to Jerramungup. Introduced from Eastern Australia	Disturbed ground
	R. bucephalophorus	Busselton to Albany	Weed of wastelands and verges
	R.conglomerates (Clustered Dock)	Moora to Albany. Native to Europe and Asia	Disturbed wetlands and creeks
	R. Crispus (Curled Dock)	Geraldton to Esperance. Native to Europe and Asia	Disturbed wetlands, creeks and sometimes paddocks
	R. frutscens (Argentine Dock)	Walpole to Albany. Native to South America	Coastal granite seepages
	R. obtusifolius (Broadleaf Dock)	Manjimup to Albany. Native to Europe	Weed of paddocks, drains and disturbed wetlands
	R. Pulcher (Fiddle Dock)	Gingin to Albany. Native to Mediterranean	Weed of pastures, waterways and wastelands
	R. vesicarius (Ruby Dock)	Common and widespread in arid areas. Often mistaken as native species. Prolific in Wheatbelt Region. Native to North Africa, Middle East and India	Road verges and disturbed areas

Food types of *Streptopelia* doves
(Extent and availability in Study Area) (Part 3)

Type	Species	Location/Description	Habitat
Acacia spp.		Wattles. Grows as trees and shrubs. Several native WA species have been planted outside natural range and naturalised new sites. Other naturalised species introduced from eastern Australia and overseas	
	A.blakelyi (Blakely's Wattle); *A. lasiocalyx* (Caterpillar Wattle); *A. microbotrya* (Manna Wattle); *A.salgna* (Golden Wreath Wattle)	Native to Western Australia. All 'tough' species with long-lived seed	Disturbed areas such as road verges. After grading and fire will naturalise away from parent plant.
	A. baileyana (Cootamundra Wattle)	Garden escape found in Jarrah Forest. Flowers in winter. Native to New South Wales	Jarrah forests and road verges
	A. dealbata (Silver Wattle)	Garden escape found intermittently through Jarrah and Karri forests near Porongurup Ranges (near Albany). Extends Perth to Albany. Flowers in spring. Native to NSW, Victoria and Tasmania	Jarrah and Karri forests. Road verges
	A. decurrens (Early Black Wattle)	Garden escape. Perth to Albany. Flowers in winter. Native in NSW	Road verges, creek lines and wastelands
	A. elate (Mountain or Cedar Wattle)	Flowers in spring. Garden escape. Grows from old plantings in Darling Range.	Creeklines
	A. farnesiana (Mimosa Bush)	Mainly up north but has reached Muchea from trucks travelling through carrying stock from northern pastoral areas. Native of South America,	Road verges, creeks, rivers, disturbed floodplains
	A. floribunda (Carkin, White or Sallow Wattle)	Flowers in spring. Spread from plantings from Dryandra and Araluen Botanical Park. Native of Queensland, Victoria and NSW	Bushland, road verges throughout Southwest
	A. iteaphylla (Flinders Range Wattle)	Flowers after break of winter rains. Spreading from plantings in Perth area. Native to South Australia	Bushland, road verges in metropolitan area
	A. longfolia (Sydney Golden Wattle) subspecies *longifolia* and *sophorae*	The latter is a garden escape. Extends from Perth to Mount Manypeaks near Albany. Native to eastern Australia	Road verges, creeklines, swamps and native bushland
	A melanoxcylon (Australian Blackwood)	Garden escape. Bright seed attractive to birds. Regenerates after disturbance to form dense thickets. Perth to Albany and Dunsborough. Potential serious weed Augusta to Albany. Native to eastern Australia	Swamps and wetlands
	A. podalyriifolia (Queensland Silver Wattle)	Winter flowering. Garden escape. Perth and metropolitan area. Native of Qld and NSW	Road verges and bushland
	A. pycantha (Golden Wattle)	Australia's floral emblem. Often confused with *A. saligna* a native of WA. Highly promoted with free seed given away. Abundant and increasing. Especially in Darling Range and Wheatbelt region. Extends Perth to Albany. Native to NSW, Qld and SA	Road verges, woodlands

Food types of *Streptopelia* doves
(Extent and availability in Study Area) (Part 4)

Type	Species	Location/Description	Habitat
	Arachis hypogea (peanut/groundnut)	Not present in WA	
	Arctocheca nivea	Not present in WA. Two others species in WA *A. Calendula* (Capeweed) Major weed. Abundant. Found all habitats throughout the Southwest. Dominating pastures. Increasing in arid zone. *A. populifolia* (Dune Arctotheca). Present on fore-dunes Perth to Esperance. Flowers in winter, spring into early summer	Crops and pastures and fore-dunes
	Cajanus cajun (Pigeon Pea)	Not present in Southwest	
	Quercus palustris (Pink Oak)	Not present in WA	
	Sorghum vulgare (Sweet Sorghum)	Restricted - used experimentally as forage fodder. WA has ten other Sorghum species, three of which are introduced. Two of these restricted to far north. Third, *S. sudanense* (Sudan Grass) extends Perth to Albany in disturbed swampy land. Flowers spring through summer. Native to Sudan.	Swamplands
	Zea mays (maize)	Restricted - conditional entry of seed in to WA	

Appendix 8: Birds introduced into Western Australia
Other than the focus species for the Present Study (Part 1)
(Based on Long, 1988, pages 6-21)

Bird Species Established in Western Australia	
Feral Pigeon	*Columba livia*
Goldfinch	*Carduelis carduelis*
Red-browed Waxbill	*Estirlda temporalis*
White Swan (Mute Swan)	*Cygnus olor*
Mallard	*Anas platyrbynchos*
Ring-necked Pheasant	*Phasianus colchicus*
Peafowl	*Parvo cristatus*
Cattle Egret	*Bubulcus ibis*
Sulphur-crested Cockatoo	*Cacatua galerita*
Rainbow Lorikeet	*Trichoglossus haematodus*
Bird Species Introduced but not Established	
House Sparrow	*Passer domesticus*
Tree Sparrow	*P. montanus*
Starling	*Sturnus vulgeris*
House Crow	*Corvus splendens*
Quail (and American Quail)	*Colinus virginianus, Lophortyx Californica Coturnix coturnix*
Helmeted Guineafowl	*Numida meleagris*
Red-legged Partridge	*Alectoris rufa*
Partridge	Possibly *perdix perdix*
Mexican Partridge	Species unknown
Geese and Ducks	Several Species
Ostrich	*Struthio camelus*
Red-billed Leiothrix	(= Pekin nightingale) *Leiothrix luta*
Skylark	*Alauda arvensis*
Musk Lorikeet	*Glossopsitta concinna*
Doves	*Geopelia humeralus, Streptopelia, Decaocto* and other species
Silver Pheasant	*Lophuri nycthemera*
Golden Pheasant	*Chrysolophus pictus*
Re-introduced and Translocated Native Species	
Noisy Scrub -bird	*Atrichornis clamosus*
Galah	*Cacatua roseicapilla*
Corellas	*C. pastinator, C. tenuirostris*
Double-barred Finch	*Poephila bichenovii*
Chestnut-breasted Finch	*Lonchura castaneothorax*

Birds introduced into Western Australia
(Other than the focus species for the Present Study) (Part 2)

Other Introductions	
Greenfinch (or Chaffinch ?)	*?*
Bullfinch	*Pyrrhula pyrrhula*
Chaffinch	*Fringilla coelebs*
Canary	*Serinus canarius*
Adelaide Rosella	*Platycercus adelaidii*
Crimson Rosella	*P. elegans*
Eastern Rosella	*P. eximius*
Chattering Lory	*Lorius garrulus*
Namaqua Dove	*Oena capencis*
Peach-faced Love Bird	*Agapornis roseicollis*
Blackbird	*Turdis merula*
Indian Myna	*Acridotheres tristis*
Jungle Myna	*A. Acridotheres fuscus*
Japanese Quail	*Coturnix Coturnix gaponica*
King Quail	*C. chinensis*
Rose-ringed Parakeet (Indian Ring-Neck)	*Psittacula krameri*
Budgerygah (Budgerigar)	*Melopsittacus undulatus*
Red-collared Lorikeet	*Trichoglossus rubritorquis*
Alexandrine Parakeet	*Psittacula alexandri*
Hooded Parrot	*Psephotus dissimilis*
Monk Parakeet	*Myiopsitta monachus*
Diamond Dove	*Geopelia cuneata*
Star Finch	*Neochmia ruficauda*
African Firetail Finch	*Lagonosticta senegala*
Orange-breasted Finch	*Estrilda subflava*
Silver Pheasant	*Lophura nycthemera*
Guineafowl	*Numida meleagris*